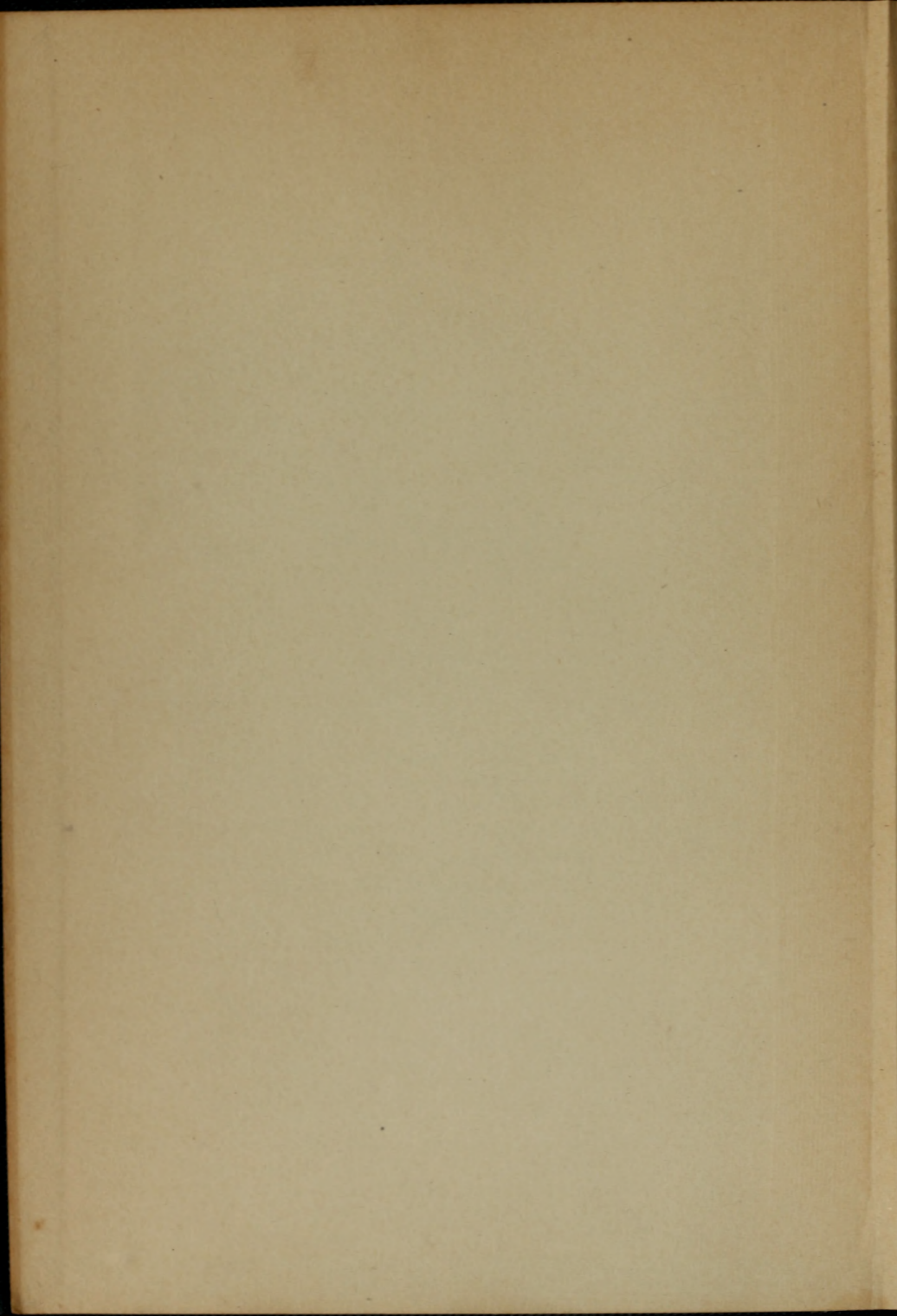
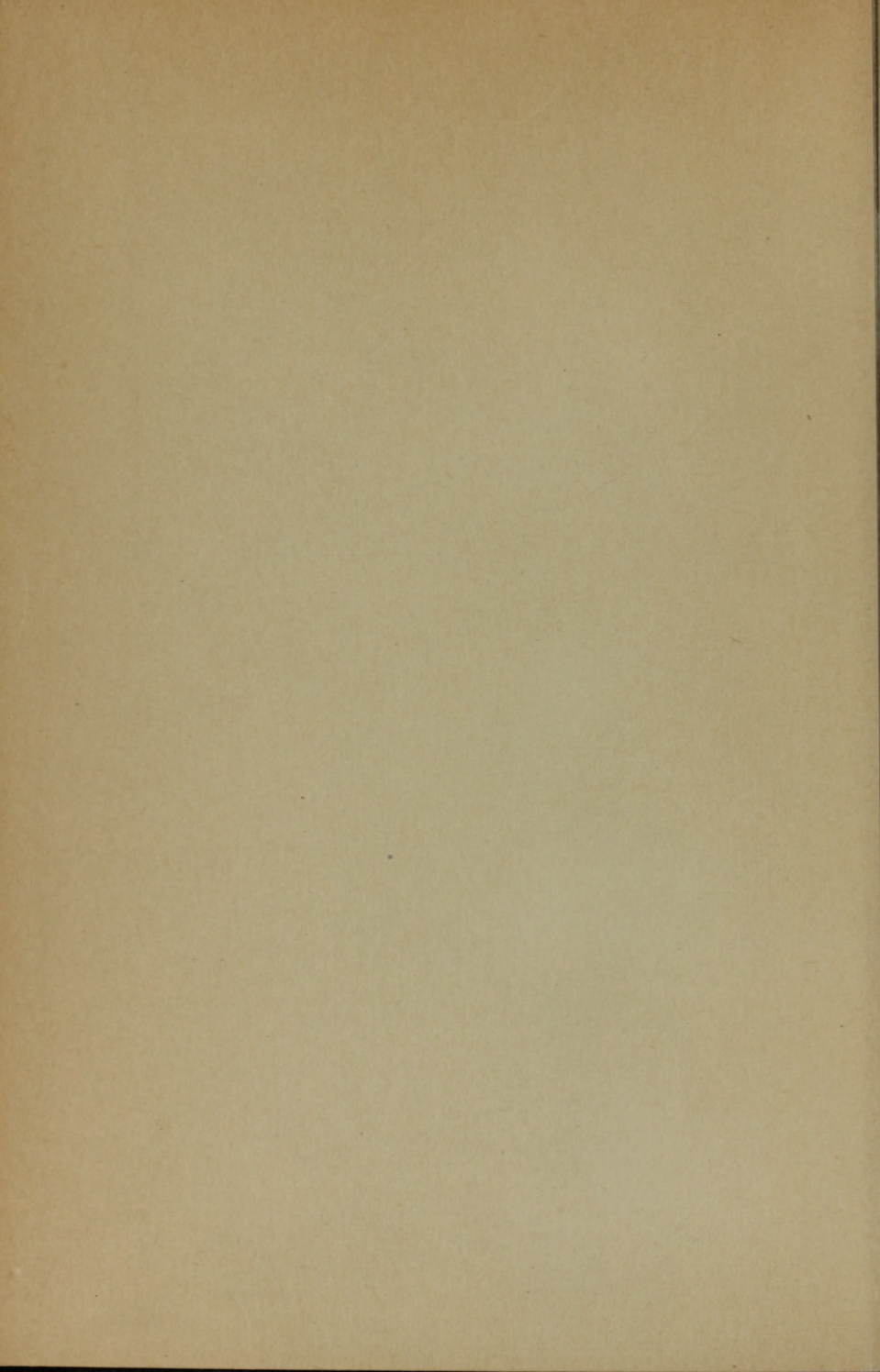
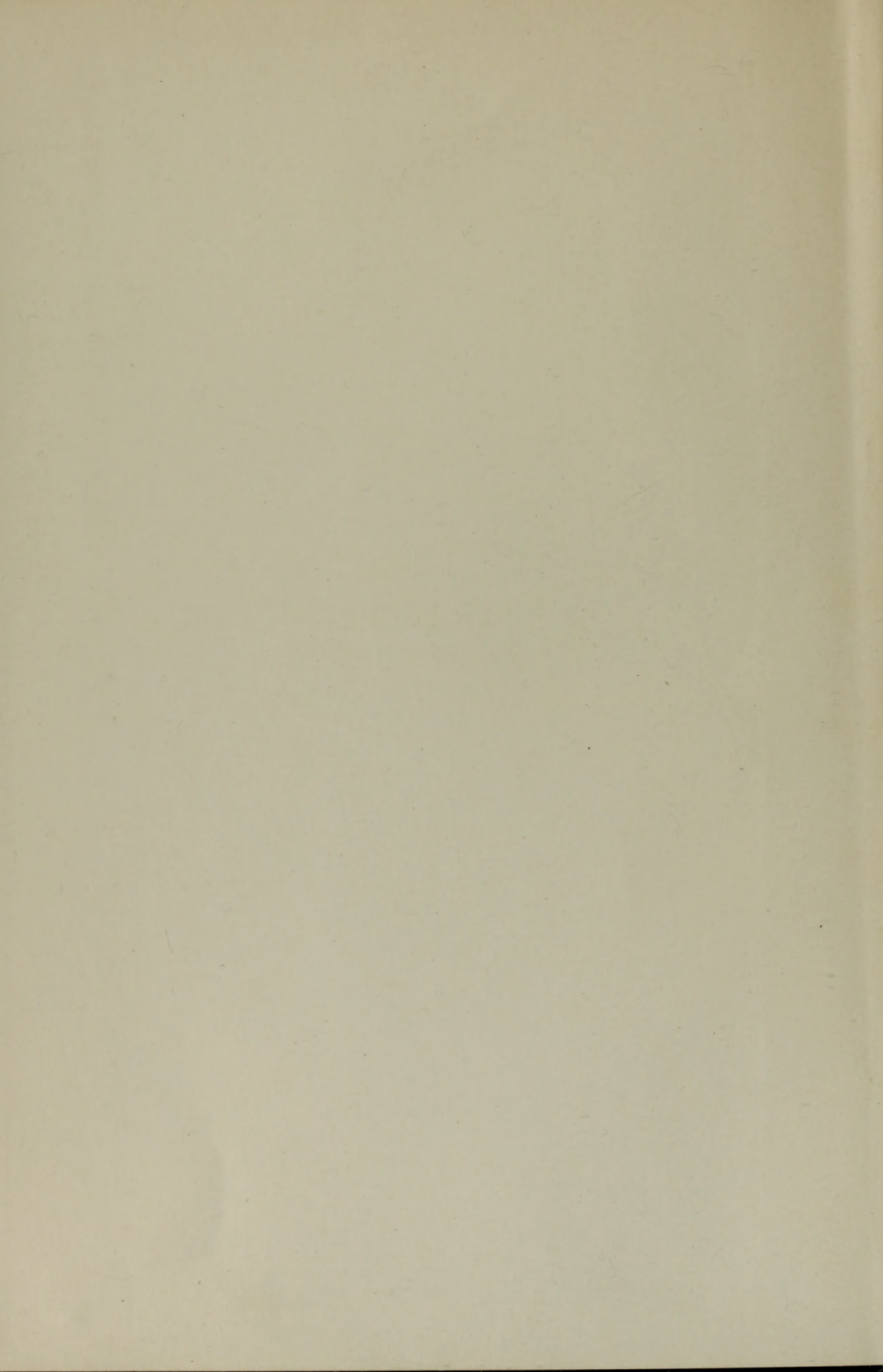
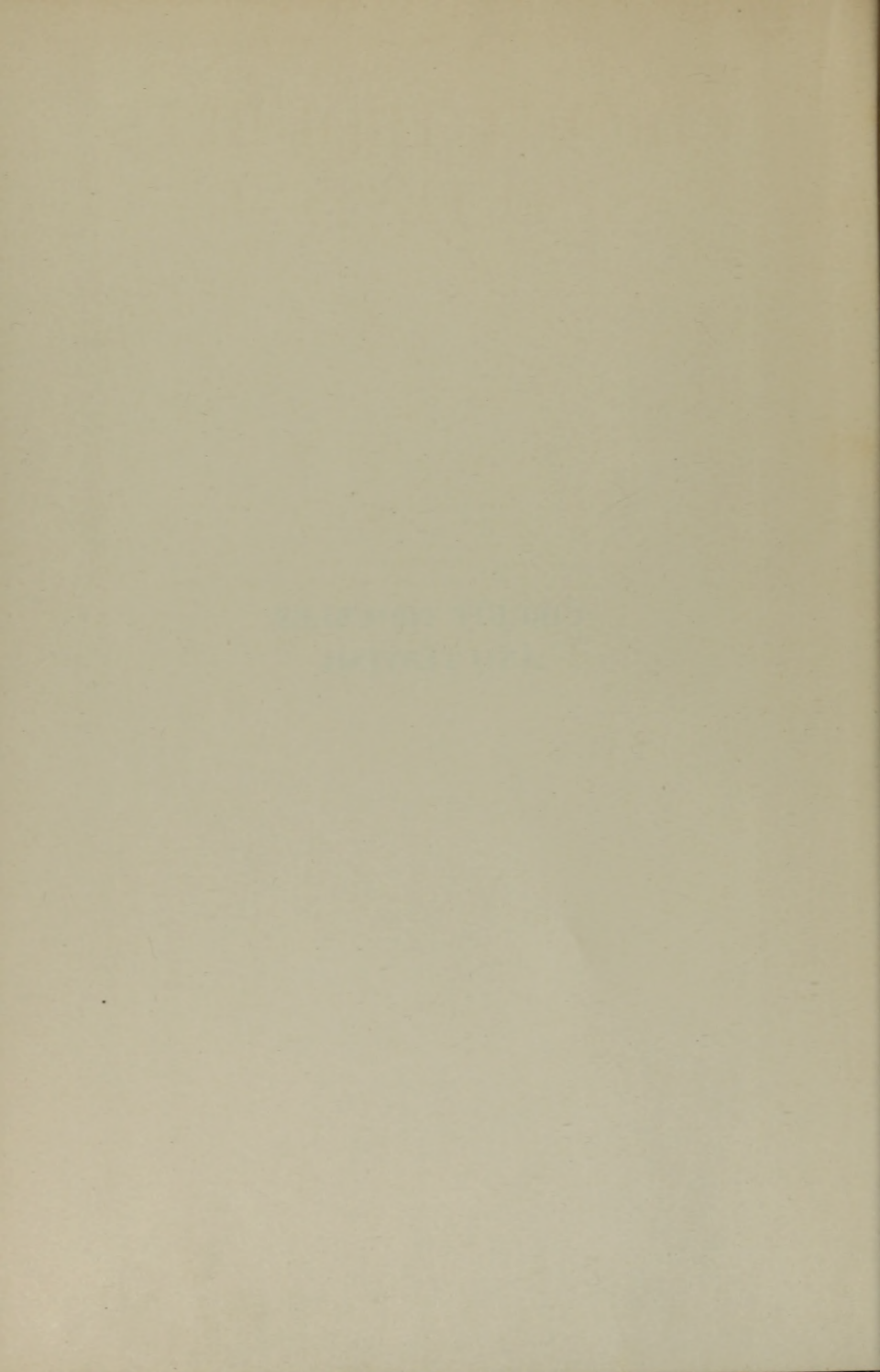








CIRCUIT TROUBLES
AND TESTING



CIRCUIT TROUBLES AND TESTING

BY

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PREFACE

There is available in book form but little information concerning power- and lighting-circuit troubles—their causes, localization and correction. Many articles and some books have appeared which deal with internal electrical troubles—those which occur within generators, motors and other apparatus, but the troubles which occur on the circuits and supply the devices have been given scant attention.

It is therefore the intention to record in this work practical discussions of the troubles which occur on power and lighting circuits and descriptions of the most effective methods of their localization and correction. Aerial pole line circuits, underground cable circuits and interior wiring circuits will be treated.

The text is so written that it can be readily understood by the men (electricians, troublemen, wiremen; and the like) who have to do the work. However technical accuracy is never sacrificed. Hence, these directions should be useful to any man, regardless of his experience and training, who wishes to obtain authoritative practical information on these subjects. For the illustrations (there are more than 230) specially prepared drawings have been made in each case. It has been the endeavor to so design and render these pictures that they will convey the desired information whether under minimum of supplementary text.

With this, as with other books which have been prepared by the editor, it is the sincere desire to render it of maximum usefulness to the reader. It is the intention to improve the book each time it is revised and to enlarge it as conditions may demand. If these things are to be accomplished most effectively, it is essential that the readers cooperate with us. This they may do by advising the author of alterations which they feel it would be advisable to make. Future revisions and additions will, insofar as is feasible, be based on such suggestions and criticisms from the readers.

Although the proofs have been read and checked very carefully by a number of persons, it is possible that some undiscovered errors may remain. Readers will confer a decided favor in advising the author of any such errors.

TERRELL CROFT.

UNIVERSITY CITY,
ST. LOUIS, MO.

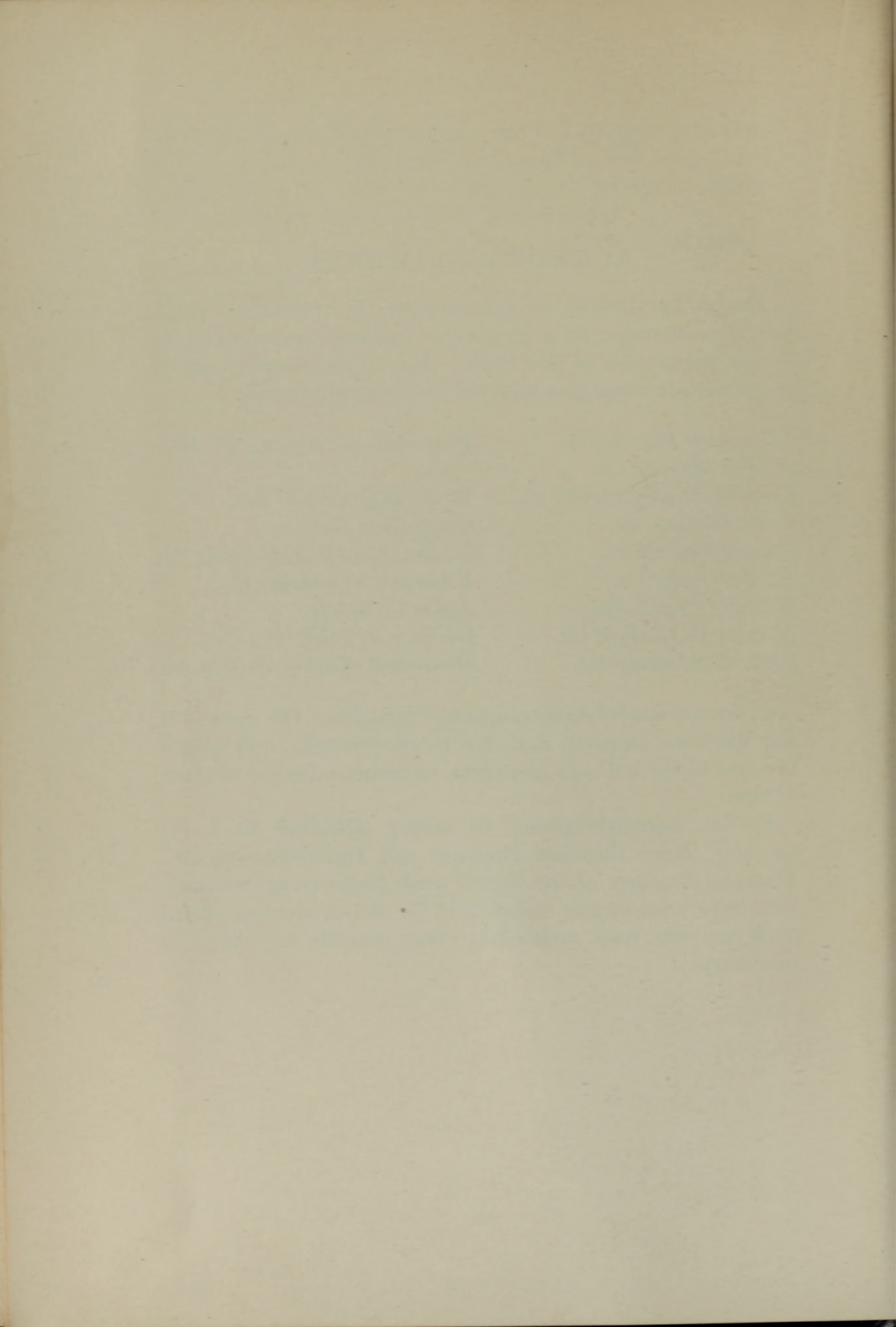
ACKNOWLEDGMENTS

The author desires to acknowledge the assistance which has been rendered by a number of concerns and individuals in the preparation of this book. Among the concerns which cooperated in supplying material for illustrations are:

<i>Fahnestock Electric Co.</i>	<i>Westinghouse Electric & Mfg.</i>
<i>Mueller Electric Co.</i>	<i>Co.</i>
<i>Frankel Display Fixture Co.</i>	<i>W. N. Matthews & Bro.</i>
<i>T. F. Johnson, Jr.</i>	<i>Queen-Gray Co.</i>
<i>General Electric Co.</i>	<i>Lundin Electric & Machine Co.</i>
<i>Electric Tester Co.</i>	<i>Eisemann Shortfinder Co.</i>
<i>Western Electric Co.</i>	<i>James G. Biddle</i>
<i>Morriss E. Leeds & Co.</i>	<i>Herman H. Sticht and Co.</i>
<i>Leeds & Northrup Co.</i>	<i>Manhattan Electric Supply Co.</i>

Other acknowledgments appear throughout the book. If any has been omitted, it is due to an oversight, and will, if brought to the author's attention, be incorporated in a future edition.

Special acknowledgment is hereby accorded to I. V. Le Bow, *Head Electrical Engineer* and Daniel Staehle, Jr., *Electrical Engineer* of the *Terrell Croft Engineering Company*, who have been largely responsible for the production of the book and who have assisted in every possible way since its inception.



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CIRCUIT TROUBLES AND TESTING

DIVISION 1

INSTRUMENTS AND DEVICES

1. The Underlying Principle, Upon Which Is Based Practically All Testing Of Circuits For Faults, is: (1) *An electromotive force—voltage—is applied to the part of the circuit which is under consideration.* (2) *Then, certain phenomena, which result from the application of this voltage, are observed.* By these observations, it may usually be determined what sort of a fault exists on the circuit and where the fault is located. To be able to locate a circuit fault, one must know where and how to apply the voltage. He must also know how to interpret the phenomena which result, due to the application of the voltage. Therefore, the purpose of this book is to explain how to do these things and thereby arrive at the correct conclusion.

2. The Purpose Of This Division is to describe some of the more simple instruments and devices which are used for testing circuits in locating faults. The order, in which the various apparatus is treated in the following pages of this division, is: (1) *Test clips and leads*, Sec. 4. (2) *Fuse-testing devices*, Sec. 7. (3) *Test-lamp sets*, Sec. 10. (4) *Battery and magneto sets*, Secs. 18 and 19. (5) *Resistance measuring devices*, Sec. 22. (6) *Tone-test apparatus*, Sec. 48. Then, in following divisions, the methods of using them in locating faults are treated.

3. NOTE.—SEVERAL DESIGNS OF THE HOME-MADE DEVICES will be illustrated. In general, any one of these home-made designs is about as good as another. The reason why several different arrangements

are shown is that most of them are made from odds and ends lying about, some of which can be found in most any shop. Thus, the reader may select the most suitable arrangement for him, in accordance with the material which is the most readily available.

4. Test Clips And Leads are necessary in nearly every sort of testing. The leads should be rubber-covered, extra flexible, stranded cable. Unless the leads are "extra flexible," con-

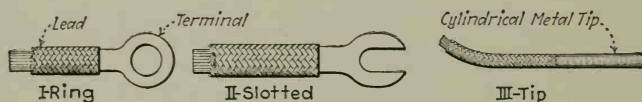


FIG. 1.—Typical terminals for test leads.

siderable difficulty will be experienced in keeping them out of the way during the test. Terminals (Fig. 1) or test clips (Figs. 2, 3, 4 and 5) should be soldered to the ends of the cable to facilitate making the connections. If the leads are to be used for connecting two instruments together both ends

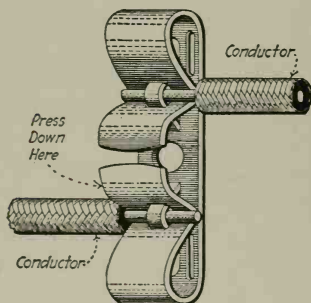


FIG. 2.—A test clip for the connecting together of two conductors. (Fahnestock Electric Co.)

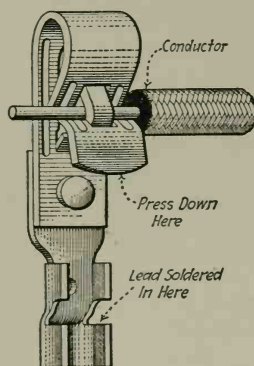


FIG. 3.—Test clip for connecting a lead to a conductor. (Fahnestock Electric Co., 129 Patchen Ave., Brooklyn, N. Y.)

of each lead should be provided with terminals (Fig. 1) of the proper type to conform to the binding posts of the instrument. Where an instrument is to be connected to a battery, or a conductor, one end of the lead should ordinarily be pro-

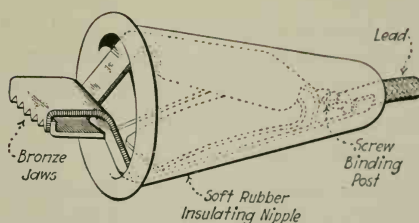


FIG. 4.—Test clip for carrying considerable current. Clips of this type are made in capacities up to 200 amp. (Mueller Electric Co., Cleveland, Ohio.)

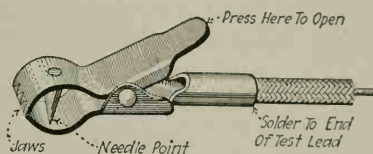


FIG. 5.—Test clip for relatively small values of current. Clips of this type are well adapted for use with a voltmeter or with a magneto test set. The jaws will grip bare binding posts, terminals or conductors. The needle point can be pierced through the insulation on conductors, and thus the voltage between lines determined without skinning the wires. (Frankel Display Fixture Co., New York City.)

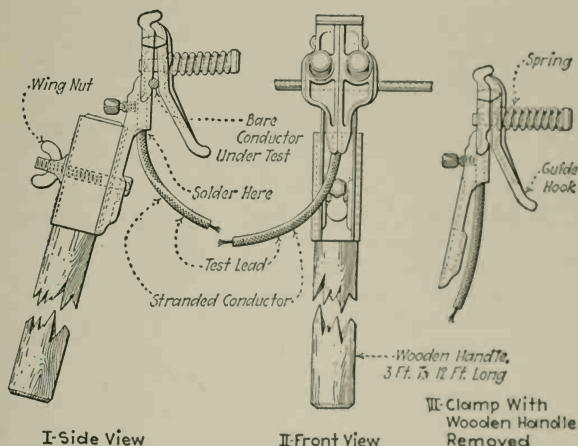


FIG. 6.—A "Johnson" clamp which may be used for a large current-carrying capacity or low-resistance test clip. By equipping the clamp with a relatively long wooden (insulating) handle it may be safely used on high-voltage lines. (T. F. Johnson, Jr., Atlanta, Ga.)

vided with a test clip (Fig. 3). Test clips of the type shown in Fig. 5 are widely used for low-voltage (telephone and signal-wiring) testing; the test leads of magnetos (Fig. 29) are often equipped with them. A heavy-duty low-resistance test clip is shown in Fig. 6. Properly-made test leads will save many times their cost during their life.

5. NOTE.—IN THOSE CASES WHERE IT IS NECESSARY TO KNOW THE RESISTANCE OF THE LEADS (Sec. 130), they should be made up and equipped with the proper terminals. Then, the resistance of each lead should be accurately determined (Sec. 130), and this value, in ohms, should be stamped on the terminal.

6. All Fuses Should Be Tested At the Time They Are Installed.—A simple fuse-testing device will be found to be

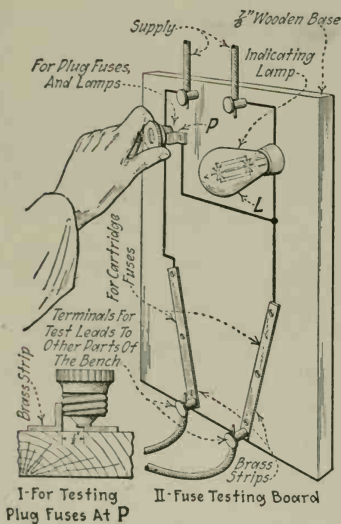


Fig. 7.—A fuse-and-lamp-testing board. (Power, p. 375, March 11, 1923.)

very useful as a time saver. Very frequently, bad fuses are inserted in the same container with good fuses. Also, it sometimes happens that the fusible conductor in a new fuse will be open. Locating a blown fuse (Div. 2) and then replacing it with another blown fuse is very annoying. This also results in a waste of time both for the electrician and the apparatus which is served by the faulty circuit. Furthermore, if a fuse blows from an overload and an open fuse is then inserted in its stead, the electrician may assume that the fuse which was just installed has been ruptured by a short-circuit or a ground. Then a lot of time may be expended in hunting for the supposed short-circuit or ground which does not exist. Arrangements for testing lamps can also be readily combined with a fuse-testing device, as shown in succeeding illustrations. Several fuse and lamp-testing devices are described below.

7. NOTE.—THE FUSE-TESTING DEVICES which are illustrated in Figs. 7, 8, 9, 10, 11, 12 and 13 are, in general, self-explanatory. When a "good" fuse is placed on the test contacts, the indicating lamp, *L*, lights. If the fuse is "bad"—is open—the indicating lamp does not light. The dimensions between the ends of the V-shaped metal strips

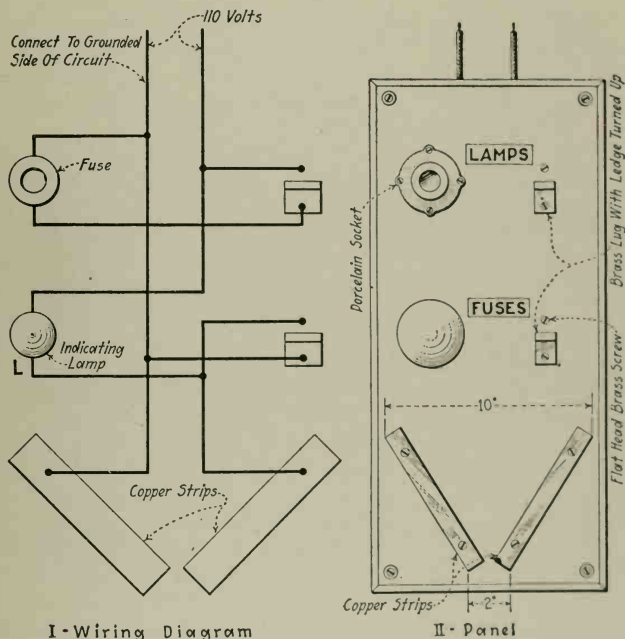


FIG. 8.—Test board for lamps, and plug and cartridge fuses. (*Electrical World*, p. 339, Aug. 14, 1920.)

for testing cartridge fuses are not given in the illustrations. This is because the necessary distances between the ends of the strips will vary according to the range of sizes of the fuses which are to be tested. If these sizes range from the smallest to the largest of the approved cartridge fuses, the distance between centers of strips at the lower part of the "V" should be about 2 in., and the distance between centers at the top of the "V" should be about 10 in.

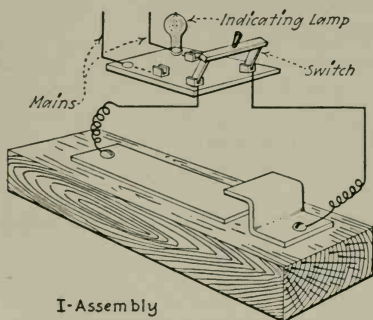
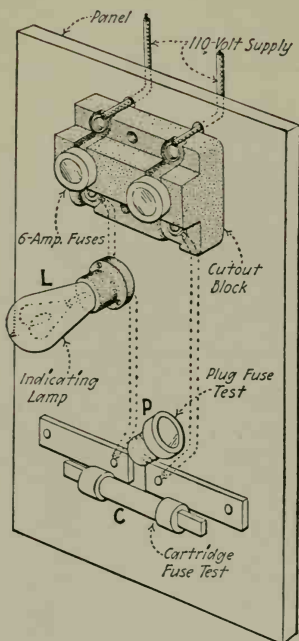
8. NOTE.—THE POCKET FLASHLIGHT FUSE TESTER shown in Fig. 13 is very convenient because the electrician may carry it in his pocket. With it he can test the fuses at a panel board. This renders it unnecessary to take the fuses to the workbench for testing. The pocket tester is made from a small, flat, nickel-plated, pocket flashlight. A $\frac{1}{4}$ -in. hole, *A*, is drilled in the metal case in the center of one side, about $\frac{1}{4}$ -in. from the bottom rim, as indicated in *I*. Two flat-head No. 6-32 screws,

s and s, $\frac{5}{8}$ in. long, are soldered to the case in line with the $\frac{1}{4}$ -in. hole and about 1 in. apart as shown. Next, a piece of $\frac{1}{16}$ -in. brass, B, $1\frac{3}{8}$ in. square, is cut with a circular notch. Two $\frac{1}{4}$ -in. holes are then drilled in this brass, 1 in. apart to fit the two screws soldered on the case. Two $\frac{1}{8}$ -in. and one $\frac{1}{4}$ -in. holes are drilled in a piece of fiber which should be about $\frac{3}{8}$ in. by $\frac{3}{8}$ in. by $1\frac{3}{8}$ in. The holes are spaced to fit over the two screws and opening as shown at I.

One end of a piece of No. 18 fixture wire about 5 in. long is looped (but not soldered) around the short battery terminal as shown at L in I and II, the insulation being left on the wire close up to this loop. Before assembling, it is good practice to file off sharp edges on the $\frac{1}{4}$ in. hole, A, in the case, to prevent cutting the insulation on the fixture wire.

The testing device is assembled as follows: After putting the loop, L, over the battery terminal, pass the other end of the wire through the hole in the case, from the inside toward the outside, through the middle of the fiber block; solder it to the brass piece as shown at I. Next, the fiber and then the brass piece are slipped over the screws. Two fiber washers are added and tightened by two

FIG. 9.—Fuse-and-lamp-testing board. (*Power*, p. 690, Nov. 6, 1921.)



II—Testing Cartridge Fuse

III—Testing Plug Fuse, Or Lamp

FIG. 10.—Test block for testing lamps, plug and cartridge fuses. (*Electrical Review and Western Electrician*, p. 290, Feb. 17, 1917.)

6-32 nuts. The fiber washers must fit into and over the $\frac{1}{4}$ -in. opening in the brass plate and must insulate the screws and nuts from the plate.

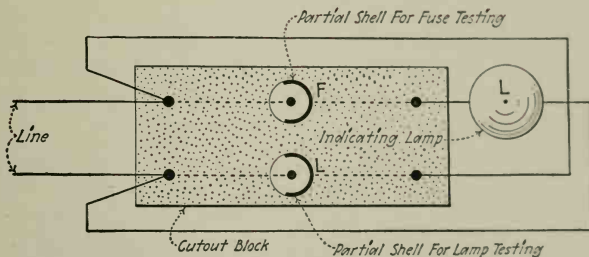


FIG. 11.—Fuse-and-lamp-testing device which is made by cutting away about one half of the screw shells on a cutout block and then spreading out the shells so that they will admit a lamp base without having to screw it in.

After the nuts are screwed down tightly, the protruding ends of the screws are cut off and the rough edges filed smooth. The battery is then wrapped with a band of one thickness of friction tape, as in II, to keep

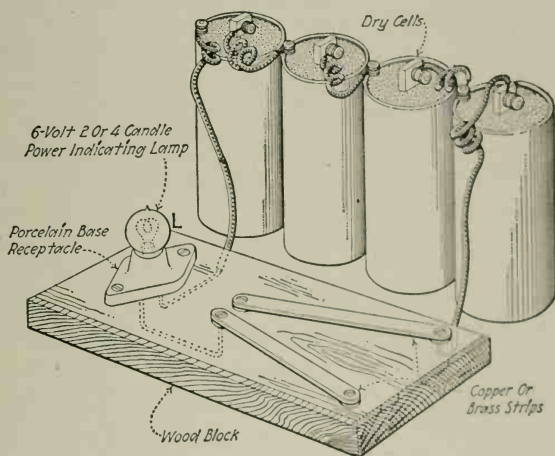


FIG. 12.—An arrangement for testing fuses which may be used when it is desired to locate the testing apparatus at a point where a 100-volt lighting circuit is not available. This arrangement is not suitable for testing 110-volt lamps. (*Popular Mechanics*.)

the fixture wire in place. This also insures a good connection and prevents the loop from interfering with the button switch. The battery is then inserted in the usual way.

The method of testing a plug fuse is shown at *IV*; the method of testing a cartridge fuse at *V*. If the fuse is "good," the lamp lights. Care must be taken when assembling, that the screws, *s* and *s*, on the case do not contact with the brass piece, *B*. This tester should not be carried in a pocket or a tool box which contain loose pieces of metal. The loose pieces might accidentally close the circuit and thus drain the battery. The modification described above will not interfere with the ordinary use of the device as a flashlight.

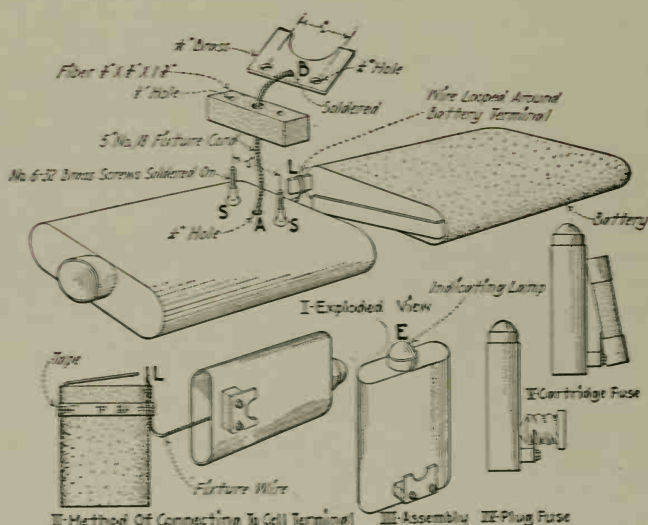


FIG. 13.—Fuse-testing device made from a pocket flashlight. (*Railway Electrical Engineer*, p. 154, May, 1923.)

9. The Lamp-Testing Devices (Figs. 7, 8, 9, 10 and 11), which are arranged on the fuse-testing board, so operate that when the base of a lamp is placed on the test contacts, the lamp which is being tested will light. If the filament of the lamp which is being tested is broken, it will not light. In Figs. 7, 9 and 10, the same set of contacts which are used for testing fuses are also used for testing lamps. This puts the indicating lamp, *L*, and the lamp which is being tested in series. Consequently, neither will be lighted to normal brilliancy. However, this is not an objection because it is not necessary that a lamp be lighted to full brilliancy to determine whether or not the filament is broken. In Figs.

8 and 11, a separate set of contacts is provided for testing lamps. With such arrangements, the lamp which is being tested will be lighted to full brilliancy and the indicating lamp will not be lighted. The principal objection to such an arrangement is that if a person is testing a plug fuse and inadvertently places it in the lamp-testing contacts, a direct short-circuit will be placed on the line and either the fuse which is being tested or the one next back on the branch circuit will be blown. Hence, the combinations of Figs. 7, 9 and 10 are usually, preferable.

10. A Test Lamp (Fig. 14) is a lamp which has conductors—usually wires—so connected to its terminals that the arrangement may be conveniently used in testing a circuit. By touching the “feeler” ends of these wires to two opposite-polarity conductors of a circuit, the lamp will light—assuming that a sufficient voltage exists between the two points which are touched. Hence, it can be readily determined whether or not there is a proper electro-motive force between the points in question. In assembling a test-lamp set, proper consideration must be given to the voltage of the circuits which is to be tested. If more than one lamp is required they are always connected in series.

If the voltage of the circuit is less than the sum of the rated voltages of the lamps which are in series, the lamps will burn at reduced brilliancy. In no case should the voltage of the circuit be less than one fourth the sum of the rated voltages of the lamps in series. The voltage of the circuit to be tested should not be greater than the sum of the several voltage ratings of the lamps. Furthermore, the wattage rating of all lamps on the set should be the same. Because of the ruggedness of the carbon filament, and the consequent ability to withstand severe service, carbon-filament lamps are preferable to those of tungsten for test-lamp service. Various schemes of assembling test-lamp sets are

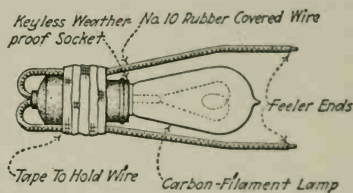


FIG. 14.—A simple test lamp.

shown in Figs. 15, 16, 17, 18 and 19, which are briefly described below.

11. NOTE.—CERTAIN FEATURES OF CONSTRUCTION OF THE TEST LAMPS which are here shown should be noted. In Fig. 15, the feelers and their support are made respectively from the blades and the fiber cross-bar of a double-pole knife switch. The switch handle is removed from the cross-bar. Then the cross-bar is drilled to accommodate a $\frac{1}{8}$ -in. pipe. A short $\frac{1}{8}$ -in. pipe nipple is screwed into the socket. The nipple is then fastened to the cross-bar with a locknut. This device can be easily manipulated about a panel board with one hand. It is convenient

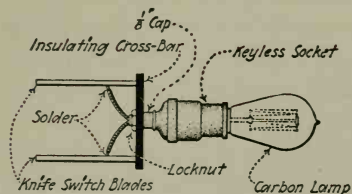


FIG. 15.—Test lamp for testing circuits on a panelboard.

for testing for blown fuses. Its principal objection is that, because of the rigidity of the feelers, it cannot be used to test across distant conductors of a circuit.

12. NOTE.—THE POCKET TEST LAMP (Fig. 16) is very convenient both because of its small size and because of the metal protecting tube which permits it to be carried in the tool bag among the other tools without danger of its being broken.

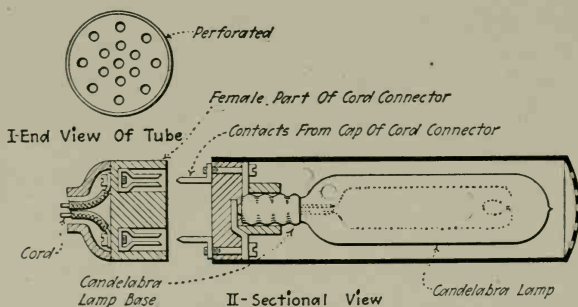


FIG. 16.—Pocket test lamp. (*Power Plant Engineering*, Feb. 15, 1920.)

13. NOTE.—THE TRANSFORMER TEST LAMP FOR 550-VOLT CIRCUITS (Fig. 17) is much more compact and more easily handled than a lamp bank consisting of five 110-volt lamps. Any small 550/110-volt transformer can be employed.

14. NOTE.—THE SOCKET-POLARITY TEST LAMP (Fig. 18) has one terminal of the receptacle connected to the center contact of the attachment plug, the other receptacle terminal is connected to the feeler.

15. NOTE.—THE DOUBLE TEST-LAMP SET (Fig. 19) is made as indicated in the illustration. It is extremely convenient around a plant which has 110-, 220- and 440-volt circuits. By using two 220 volt lamps

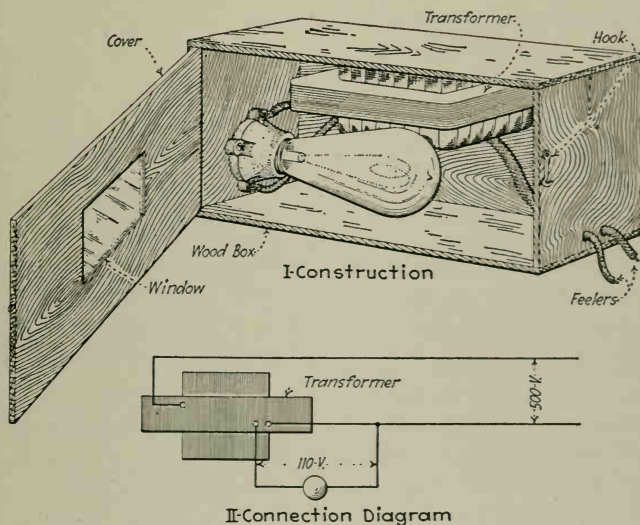


FIG. 17.—Test lamp for use on 550-volt alternating-current circuit. The transformer is from the no-voltage release mechanism of a K-20 General Electric Co. oil circuit breaker.

in the sockets, they will burn at normal brilliancy across 440 volts. If one of the 220-volt lamps is removed and a plug fuse is inserted in its place, the remaining lamp will burn at full brilliancy across 220 volts.

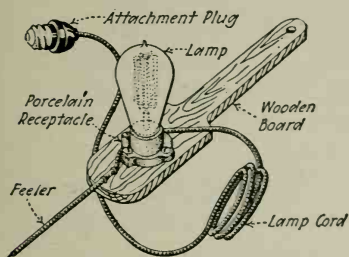


FIG. 18.—Test lamp for testing polarity of the screw shells of sockets. (*Electrical World*, p. 555, Mar. 6, 1920.)

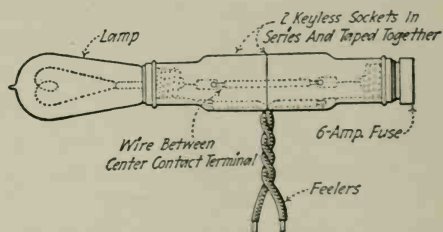


FIG. 19.—Test-lamp set for 110-220 or 440 volts. The two sockets are connected in series.

If two 220-volt lamps are used and the set is connected to a 110-volt line the filament will have only a very dull red glow; if connected across 220-volts the filament will be a bright red.

16. Test-Lamp "Feelers" (Figs. 20 and 21) should consist of a pencil of a stiff conductor material, and all but the tip should be covered with some sort of insulation. The stiffness is to provide convenience in handling. The insulation is to

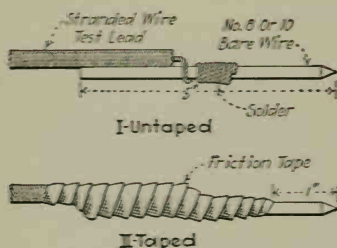


FIG. 20.—Test-lead "feeler" made from a piece of heavy wire.

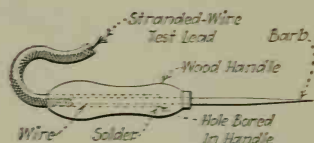


FIG. 21.—Test-lead "feeler" made from an ice pick.

prevent the user from getting a shock. Feelers may be made, as indicated in Fig. 20, from a piece of No. 8 or 10, copper or galvanized-iron bare wire. About 5 in. of such wire is soldered to the stranded-wire test lead. Then a thick covering of friction tape is served on over the bare wire to within about 1 in. of the sharpened tip. A feeler constructed of an ordinary wood-handle ice pick is shown in Fig. 21. A hole is bored in the handle and the barb removed. The test-lead wire is soldered to the barb. The barb is then inserted into the handle as indicated.

17. A Commercial Test-Lamp which may be purchased on the market is shown in Figs. 22 and 23. This arrangement is very convenient, inasmuch as it can be used for testing circuits of from 100 to 600 volts. With the cover on (Fig. 22), the lamp can be observed through the peep hole. The lamp (L , Fig. 23), which is a 110-volt candelabra-base lamp is connected in series with a resistance, R . On circuits above 220 volts, all of this resistance is left in the circuit. This prevents the lamp from burning out. When testing circuits below 220 volts, the button (B , Fig. 23) is pushed inward. This opens the connection between S and A , and closes S to contact C . Thus, a portion of the resistance R is cut out of the lamp circuit.

18. A Battery Test Set (Fig. 24) usually consists of one or more dry cells, a bell or buzzer (Fig. 24-I), a telephone receiver (Fig. 24-II), or a voltmeter (Fig. 24-III), which are connected in series. When

the circuit of the test set is completed by touching the two feelers to a continuous conductor, the bell will ring, the receiver will click, or the voltmeter hand will move. If the conductor to which the two feelers are touched is not continuous—open or broken—the above-mentioned signals will not be obtained. Various convenient and

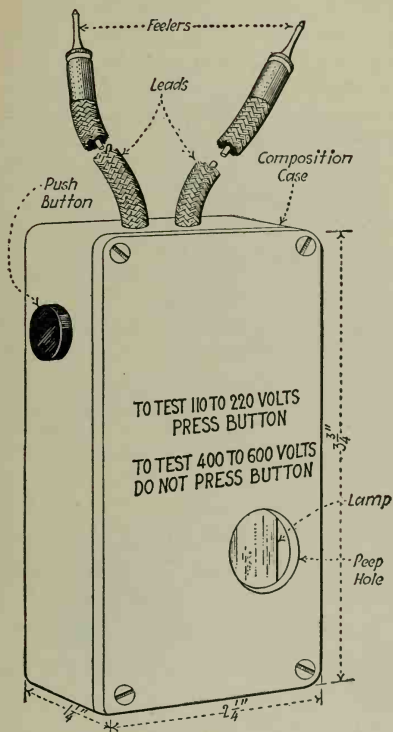


FIG. 22.—A test-lamp which can be used for testing circuits of from 100 to 600 volts. It is called "The Universal Fuse And Circuit Tester." (*Electric Tester Company.*)

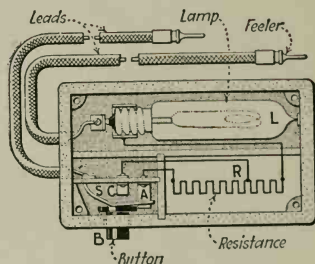


FIG. 23.—View of the test-lamp shown in Fig. 39 with cover removed, indicating the internal connections.

compact arrangements of battery test sets are illustrated in Figs. 25, 26, 27 and 28, which are self-explanatory.

19. A Magneto Test Set (Fig. 29) usually consists of a "polarized" electric bell connected in series with a small hand-operated alternating-current generator. The winding of the generator is generally placed on its armature. The excitation is provided by permanent magnets of the horse-shoe type. When the crank (C, Fig. 29) is turned an alter-

nating electromotive force is generated. If the circuit is closed by connecting a continuous conductor to the leads, *L*, while

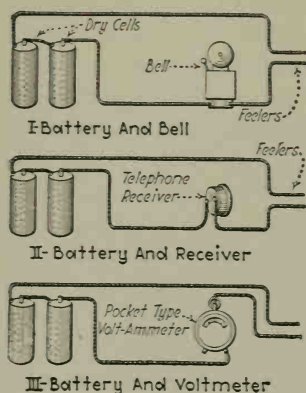


FIG. 24.—Wiring diagrams of battery test sets.

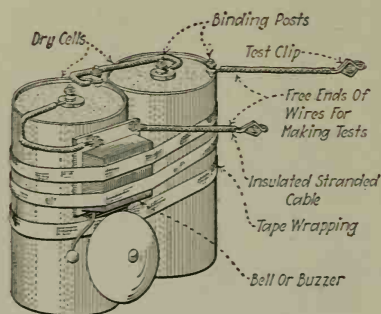


FIG. 25.—Compact arrangement of a bell-and-battery test set.

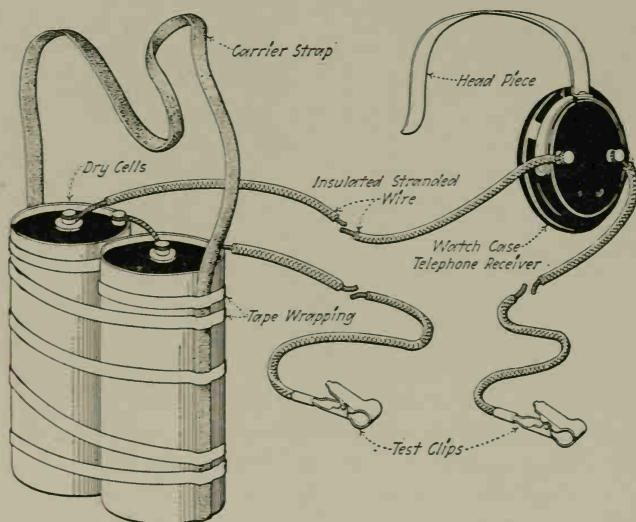


FIG. 26.—A battery-and-receiver test set equipped with test clips.

the crank is being turned a current will flow through the circuit and the bell will ring. If the conductor which is connected to the leads is open or broken the bell will not ring.

20. NOTE.—A MAGNETO TEST SET SHOULD NOT BE USED IN TESTING LONG LINES, NOR COILS WHICH HAVE A LARGE NUMBER OF TURNS WITH AN IRON CORE.—If a long line (Fig. 30-I) is “rung out” with a magneto ringer, the bell may ring, thus indicating a short-circuit when, actually, none exists. The reason for this false indication is that the long line has a high capacitance (considerable electrostatic capacity) and the alternating current which flows through the magneto in alternately charging the two conductors to positive and negative potentials, is sufficient to ring the bell. In other words, the two long conductors, which constitute the line, form a condenser and an alternating current will “flow through” a condenser. In attempting to ring out a coil which has a high inductance, such as the shunt-field coil of a direct-current motor or

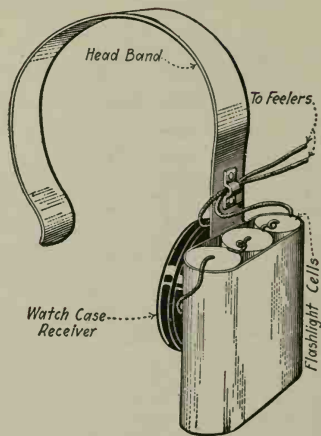


FIG. 27.—Self-contained head set for testing work.

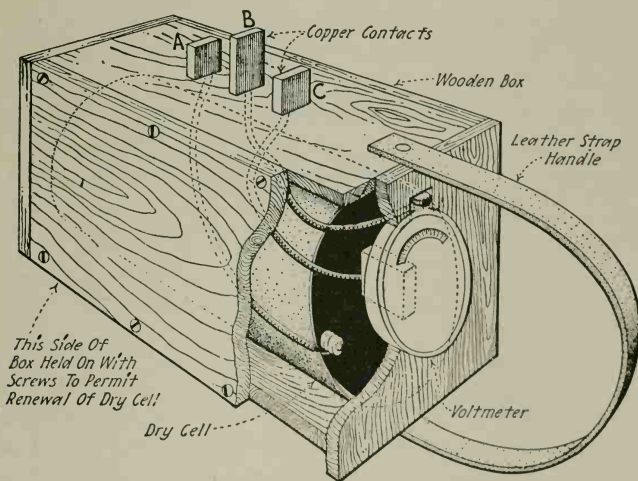


FIG. 28.—Battery-and-voltmeter test set, designed particularly for testing portable extension cords. Contacts A and B are for testing a circuit; an attachment plug may be bridged between A and B. Contacts B and C are for testing another dry cell. The carbon pole of the dry cell connects direct to the ammeter case; a spiral spring in the bottom of the box presses the carbon against the case.

generator, it may be found that the bell will not ring, thus indicating an open circuit. But the circuit may not be open. The reason the bell does not ring, even when the circuit is closed, is because the high impedance of the inductive winding to alternating current does not permit sufficient current to flow through the magneto to ring the bell.

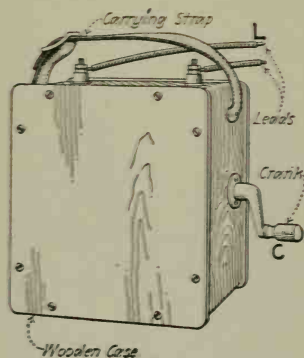


FIG. 29.—A testing magneto. The polarized bell is protected within the box. (Western Electric Co., Chicago.)

21. NOTE.—TESTING MAGNETOS ARE RATED IN ACCORDANCE WITH THE AMOUNT OF NON-INDUCTIVE RESISTANCE THROUGH WHICH THEY WILL RING.—Thus, a 10,000-ohm magneto test set will, when its crank is turned, ring its bell when a non-inductive resistance of anything less than 10,000 ohms is connected between its terminals. Standard ratings of stock commercial magneto test sets are: 10,000 ohms; 35,000 ohms; 50,000 ohms; and 100,000 ohms.

22. Resistance Measuring

Devices will now be treated. These devices include Wheatstone bridges, meggers, megohmmers, and voltmeters.

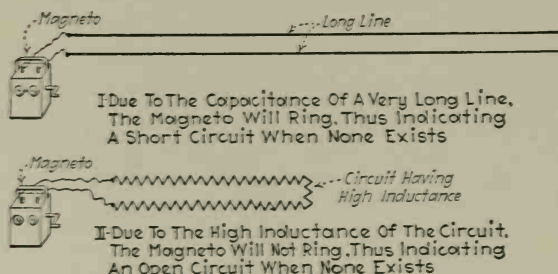


FIG. 30.—Erroneous indications which may be given by a magneto-test set.

23. The Wheatstone Bridge (Fig. 31) is a combination of conductors, devised for measuring resistance, wherein the unknown resistance is compared directly to a standard resistance without the use of calibrated measuring instruments. The principle of the Wheatstone bridge and some of the commercial designs which are used in locating faults are explained in the following sections. The methods of using

the apparatus, for locating short-circuits and grounds, are described in Div. 2.

24. The Principle Of The Wheatstone Bridge may be briefly stated as: The adjustment of the resistance of two parallel-connected conductors so that the potential difference between a given point on one of the conductors and a given point on the other conductor is zero. In Fig. 31, MPN and MQN are the parallel-connected conductors. The two *given points* are P and Q . And A , B and R are known resistance which can be varied. That is, the resistance of A , B , and R can be changed at the will of the operator, and, at any time, the operator knows the value, in ohms, of each of these resistances. The resistance X is the one, the value of which is unknown; in the diagram (Fig. 31) it represents the conductor whose resistance it is desired to measure. It is termed the *unknown resistance*. The two arms of the bridge A and B are called the *ratio arms*. Arm R is called the *rheostat arm*. In determining the resistance of a conductor with the Wheatstone bridge, the connections are made as indicated diagrammatically in Fig. 31. Resistance A , B and R are then so adjusted that when both keys are closed the reading of the galvanometer, G (Sec. 25) is zero. When this adjustment is obtained, the value of the unknown resistance, X is obtained by substitution in the following formula:

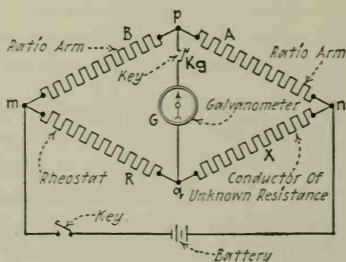


FIG. 31.—Schematic diagram of a Wheatstone bridge.

$$(1) \quad X = R \times \left(\frac{A}{B} \right) \quad (\text{ohms})$$

Wherein: X = the resistance, in ohms, of the conductor which is being measured. R , A and B are the resistances, in ohms, of the respective arms of the bridge as indicated in Fig. 31. The formula is known as the Wheatstone bridge formula. See its derivation below and also the following example:

25. DERIVATION OF THE WHEATSTONE BRIDGE FORMULA.—The galvanometer G , Fig. 31, is an instrument which is sensitive to very small values of current. Thus, with the key, K , closed, a difference in potential between p and q will cause a current to flow through the galvanometer, G . This current will produce a deflection in the galvanometer. The direction in which the galvanometer is deflected will depend upon whether p is at a higher or lower potential than q . If p and q are at the same potential—potential difference between p and q is zero—no current will flow through the galvanometer. Consequently its deflection will be zero. Thus, when the resistance, A , B and R are so adjusted that the deflection of the galvanometer is zero, then the following conditions must exist:

(a) *The voltage drop between m and p = The voltage drop between m and q .*

also

(b) *The voltage drop between n and p = The voltage drop between n and q .*

Furthermore, since no current is flowing through the galvanometer:

The current through A = The current through B ,

and

The current through R = The current through X . If the value of the current through A and B is I_1 , and that through R and X is I_2 , the voltage drop between m and p = $I_1 \times B$; the voltage drop between m and q = $I_2 \times R$; the voltage drop between n and p = $I_1 \times A$; and the voltage drop between n and q = $I_2 \times X$. Therefore, from (a) and (b) above:

$$(2) \quad I_1 \times B = I_2 \times R$$

$$(3) \quad I_1 \times A = I_2 \times X$$

Dividing For. (3) by For. (2), there results

$$(4) \quad \frac{I_1 \times A}{I_1 \times B} = \frac{I_2 \times X}{I_2 \times R}$$

From which

$$(5) \quad \frac{A}{B} = \frac{X}{R}$$

Multiplying For. (5) by R :

$$(6) \quad X = R \times \left(\frac{A}{B} \right)$$

Which is For. (1).

Note that neither the resistance of the galvanometer circuit nor of the battery circuit enters into the formula. Consequently, the resistance of these two circuits may be any desired value without affecting the accuracy of the formula.

26. EXAMPLE.—In determining the resistance of a conductor by a Wheatstone bridge, it was found that when the resistance A , B and R (Fig. 31) were so adjusted that the galvanometer reading was zero, the resistance in arm A was 10 ohms, that in arm B was 100 ohms and

that in arm R was 1,320 ohms. What was the resistance of the conductor? SOLUTION.—By For. (1), *The resistance of the conductor* = $X = R \times \left(\frac{A}{B}\right) = 1,320 \times (10 \div 100) = 1,320 \times 0.1 = 132.0 \text{ ohms}.$

27. The Principal Types Of Commercial Wheatstone Bridges, as designed for use as portable testing sets, are: (1) *The plug type*, Secs. 28 and 33. (2) *The dial type*, Sec. 35. (3) *The slide-wire type*, Sec. 40. Such sets usually contain the necessary batteries and galvanometer mounted inside the case. However, provision is ordinarily made for connecting an external battery and galvanometer to the bridge. Wheatstone bridges of each of these types are manufactured in different designs. In order that the reader may become familiar with the general construction of each, typical designs are described in following sections.

28. A Plug-Type Wheatstone Bridge Of The Postoffice Pattern is illustrated in Fig. 32. In this bridge, the resistance

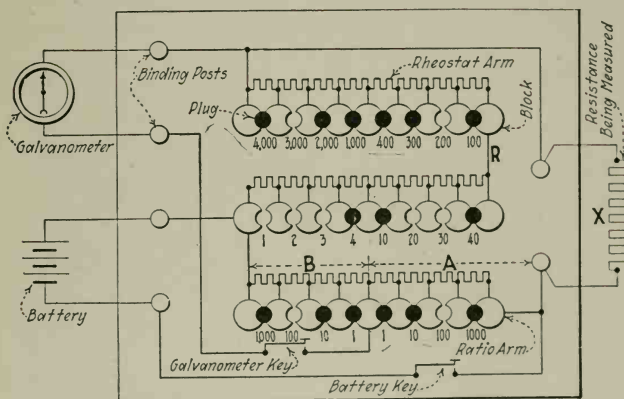


FIG. 32.—Diagram of a Wheatstone bridge of the postoffice pattern.

units are connected in series with each other. A tap is brought out from each resistance unit to a copper block. The resistance of these taps and blocks is so small that it is negligible. A number is stamped in each space between the blocks. These numbers represent the resistance, in ohms, of the resistance units which are connected between the respective blocks. When a plug is inserted between two blocks the

resistance unit which is connected between two blocks is short-circuited out of the circuit. When a plug is removed from between two blocks the resistance unit between the two blocks is placed in the circuit. Hence, the value of the resistance in each arm of the bridge is calculated by adding the numbers which are in those spaces between blocks which contain *no* plugs. The unknown resistance is computed by the Wheatstone bridge formula (Sec. 25) as explained in the example below. The bridge is provided with lugs, to which the conductor whose resistance is to be measured can be conveniently connected.

29. EXAMPLE.—In measuring the resistance X in Fig. 32, the galvanometer reads zero when the bridge was plugged as shown. What was the resistance of X ? **SOLUTION.**—The total resistance of the rheostat arm R is obtained by adding the numbers between the unplugged blocks. Therefore, $R = 3,000 + 200 + 30 + 20 + 3 + 2 + 1 = 3,256$ ohms. In ratio arm A , 100 ohms is unplugged. Also, in ratio arm B , 100 ohms is unplugged. Therefore, $R = 3,256$; $A = 100$; $B = 100$. Substituting in For. (1), $X = R \times \left(\frac{A}{B}\right) = 3,256 \times (100 \div 100) = 3,256$ ohms, which is the resistance of the conductor X .

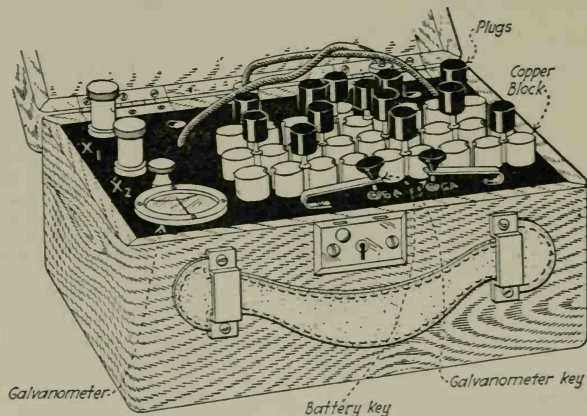


FIG. 33.—A postoffice Wheatstone bridge. (Morriss E. Leeds & Co.)

30. A Postoffice Wheatstone Bridge Which May Be Conveniently Used For Fault Location is shown in Fig. 33. A circuit diagram of this bridge is shown in Fig. 34. It is conveniently portable and can be used for necessary resistances

ranging from a fraction of an ohm to a few megohms. A *megohm* is 1,000,000 ohms. It is also arranged for convenient connections for the location of faults by the Murray-and Varley

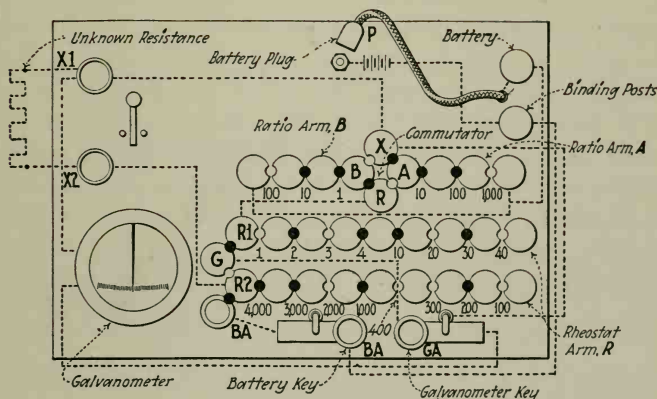


FIG. 34.—Circuit diagram of the Wheatstone bridge which is shown in Fig. 29. The dotted lines represent internal connections.

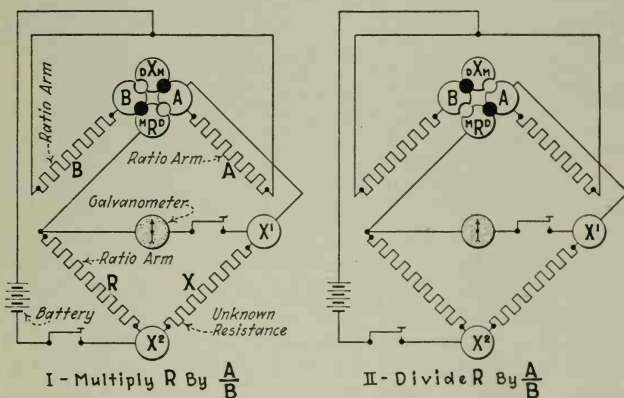


FIG. 35.—Circuit diagram of bridge in Fig. 29, showing how the changing of positions of the plugs in the commutators transposes the ratio arms A and B.

loop methods (Sec. 104 and 106). A dry-cell battery and a D'Arsonval galvanometer are contained within the case. The method of determining the resistance in each arm is the

same as that explained in Sec. 24. It will be noted from Fig. 34 that the ratio arms A and B are not directly connected to arm X and arm R as indicated in the theoretical diagram of Fig. 31, but are connected to two blocks, A and B . Two other blocks X and R are connected respectively to the unknown resistance X and to the rheostat arm R . As indicated in Fig. 35, the ratio arms A and B are connected to arms R and X through the four blocks X , A , R and B . This scheme enables the ratio arms A and B to have their relative positions changed with respect to arms X and R . It will be noticed that on blocks X and R are the small letters D and M . These stand for "divide" and "multiply." When the plugs are placed on the diagonal MM (Fig. 35-I), the resistance of X is obtained by multiplying R by $\frac{A}{B}$. When the two plugs are placed in the diagonal DD (Fig. 35-II), the resistance of X is obtained by dividing R by $\frac{A}{B}$. See the following explanation and examples.

31. EXPLANATION.—To measure a resistance with the bridge shown in Figs. 33 and 34, proceed as follows. Place the battery plug P , (Fig. 34) in position on the pin which is designed to receive it; this connects the battery circuit. Connect the conductor whose resistance is to be measured to binding posts X_1 and X_2 . Unplug 100 ohms in ratio arm A and 100 ohms in ratio arm B . Plug block R_1 to block G , and plug block R_2 to block Ba_1 . Unplug a coil in the rheostat arm R , say 1,000 ohms. Close the battery key and immediately afterward close the galvanometer key. If the galvanometer deflects toward the *plus*, more resistance must be unplugged in arm R . If the galvanometer deflects toward the *minus*, too much resistance has already been unplugged in R . Bear this in mind and continue to put in or take out plugs until the galvanometer stands at zero. In this case (same value unplugged in A and B), the reading of R (Sec. 30) is the resistance of the conductor which is being measured. For many values of resistance an even ratio of arms A and B does not give the best results. A table of values is furnished with most bridges, which gives the resistances to be unplugged in arms A and B for different ranges of resistances which are to be measured.

32. EXAMPLE.—In measuring the resistance of a conductor which was connected to X_1 and X_2 in Fig. 34, the galvanometer was balanced with the plugging shown. What was the resistance of the conductor? **SOLUTION.**—The value of the resistance which is unplugged in arm A is 1,000 ohms. The value of the resistance which is unplugged in arm B

is 100 ohms. Therefore, $\frac{A}{B} = 1,000 \div 100 = 10$. The total resistance unplugged in arm $R = 2\,000 + 400 + 300 + 100 + 40 + 20 + 3 + 1 = 2,864$ ohms. The commutator plugs, are plugged in (Fig. 35-I) on the diagonal MM . Therefore, R must be multiplied by $\frac{A}{B}$ to obtain X . Or, $X = R \times \left(\frac{A}{B}\right) = 2,864 \times 10 = 28,640$ ohms, which is the resistance of the conductor. Note that if the galvanometer had been balanced with the commutator plugged on the diagonal DD (Fig. 35-II), the resistance of the conductor would have been: $R \div \left(\frac{A}{B}\right)$, or $2,864 \div 10 = 286.4$ ohms.

33. A Plug-Type Wheatstone Bridge Of The Decade Pattern is shown in Fig. 36. A circuit diagram of this bridge

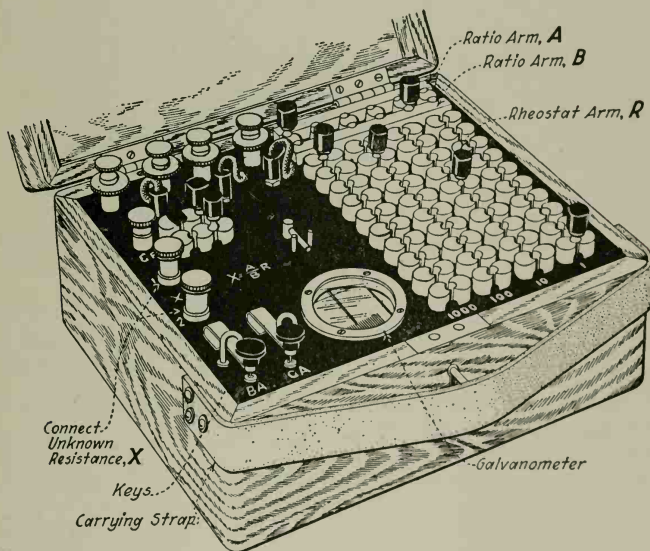


FIG. 36.—A decade Wheatstone bridge of the plug type. (Leeds & Northrup Co.)

is shown in Fig. 37. The rheostat arm (R , Figs. 36 and 37) may be considered to consist of 36 (actually there are only 16) resistance units which are arranged in 4 horizontal rows by 9 vertical rows. Each coil in the vertical row has a resistance which is 10 times the resistance of the next coil on its

right. Thus coil No. 2 in the "1,000" vertical row (Fig. 37) has a resistance of 2,000 ohms, and coil No. 2 in the "100" vertical row has a resistance of 200 ohms. Only one plug is required in each vertical row, and it must always be in use while a test is being made. The value of the resistance in

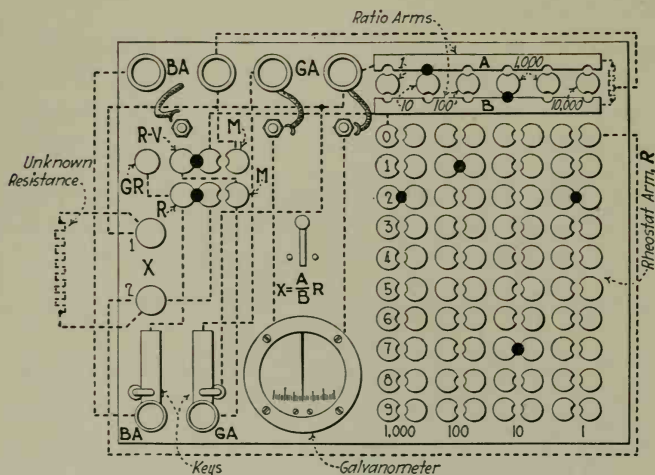


FIG. 37.—Diagram of connections of the plug decade Wheatstone bridge shown in Fig. 32.

the rheostat arm is very easily read (see Fig. 37). The resistance as shown in the rheostat arm, R , is 2,172 ohms. Another convenience of this bridge is that the ratio arms A and B are so arranged that one plug only must always be used in each, and regardless of their arrangement the unknown resistance is always computed by: $X = R \times \left(\frac{A}{B}\right)$.

34. NOTE.—SOME OF THE FEATURES OF THE PLUG DECADE WHEATSTONE BRIDGE which is shown in Figs. 36 and 37 are:

(1) The terminal which is marked "Gr" (ground) and the blocks MM enable the bridge to be used for locating faults by the Murray-or Varley-loop methods (Secs. 104 and 106).

(2) The galvanometer and batteries which are contained in the case of the instrument may be used separately for any desired purpose, or an outside galvanometer or battery may be used with the bridge.

(3) Only one plug is required for each row of resistances, and they must always be in use. This is a considerable advantage over the postoffice

type of bridge (Sec. 28). In the postoffice bridge it is necessary to withdraw the plugs and lay them aside, thereby bringing in the possibility of corroding and losing them. The use of only one plug to a row (decade) makes it more easy to ascertain that all plugs are seated snugly in the blocks. The decade bridge is much easier to read than is the postoffice bridge. The distance between rows of blocks in the decade bridge renders the plugs very easy to manipulate, even when the operator must wear gloves.

35. A Wheatstone Bridge Of The Dial Type which is constructed on the decade pattern is shown in Fig. 38. It is

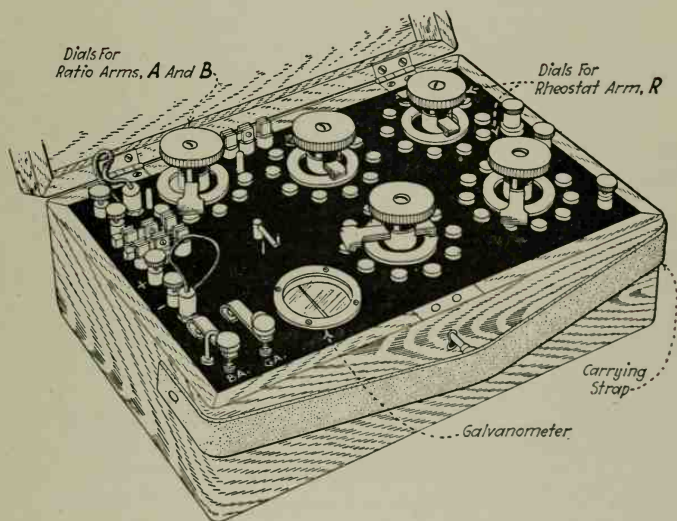


FIG. 38.—A dial decade Wheatstone bridge. (Leeds & Northrup Co.)

similar in operation to the plug decade bridge which is described in Sec. 33. However, instead of plugs, the resistances are varied by the operation of the dial switches. This has the advantage of quicker manipulation than plugs. However, the contact resistance of the dial switches in the rheostat arm is more likely to be a source of error than is the contact resistance of the plugs in a plug type bridge. It will be noticed from Fig. 39 that the connections are so arranged that the contact resistance of the ratio arms *A* and *B* is in the battery circuit behind the resistance units. This prevents any error due to the contact resistance of this particular dial switch.

The principal feature of this bridge is that the resistance units in the ratio arms *A* and *B* are so arranged that the quantity $A \div B$ is direct reading. Consequently, when the bridge is adjusted so that the galvanometer reading is zero the value of the unknown resistance *X* is computed merely by multiply-

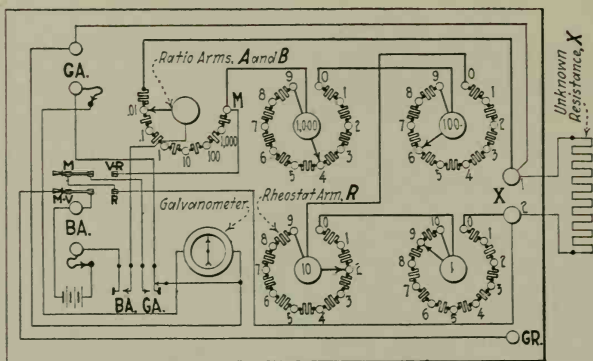


FIG. 39.—Diagram of connections of the dial decade bridge in Fig. 34.

ing the reading of the rheostat arm *R* by the reading of the *A-and-B* dial. See the following example.

36. EXAMPLE.—What is the value of the resistance of *X* in Fig. 39 if the galvanometer stands at zero with the switches in the positions indicated. **SOLUTION.**—The reading of *R* is 4,629 ohms. The reading of *AB* is 0.01. Therefore, the resistance of *X* = $4,629 \times 0.01 = 46.29$ ohms.

37. Care Of Bridge.—In order that a bridge or resistance box may remain in first-class condition, it must be carefully protected from dust and moisture by being covered when it is not in use. To insure high insulation the top must be kept clean, especially between the blocks. The plugs must be kept free from grit, grease or from contact with mercury. Grease may be removed by the use of a little benzol. Never use sand or emery paper for cleaning the plugs or holes, for the surfaces of the taper will be spoiled by this treatment. These materials work into the metal and cannot be removed, thus causing the plugs to “cut.” If it becomes absolutely necessary to clean the plugs and sockets, a little of the very finest whiting may

be employed. Extra holes of the proper taper bored in the brass blocks are convenient for holding the plugs when they are not in use, and also for attaching a movable terminal. Never apply undue force in inserting the plugs.

NOTE. PRECAUTIONS IN MAKING WHEATSTONE-BRIDGE MEASUREMENTS.—The following rules should be observed in using a Wheatstone bridge:

1. Do not employ a battery having an e.m.f. of over 5 volts; a lower value is desirable if sufficient sensitiveness can be obtained.
2. Always shunt the galvanometer during preliminary adjustments. The shunt circuit should be opened when the final balance is made.
3. See that all binding posts are screwed up tightly and all plugs firmly inserted. After withdrawing a plug those adjacent to it should be retightened.
4. For a preliminary balance use a 1 to 1 ratio.
5. In manipulating the keys be careful not to touch the metal work, as the heat and moisture of the hand is likely to set up appreciable electromotive forces.
6. Always close the battery switch first and then the galvanometer switch, to avoid momentary deflections of the galvanometer due to the transient e.m.f.'s set up while the currents are establishing themselves.
7. If the contact or lead resistances are appreciable, relative to the resistances of the coils with which they are in series, these resistances should be separately determined.

39. In General, Most Of The Commercial Forms Of Wheatstone Bridges Are Not Well Adapted For Locating Faults On Power And Lighting Circuits.—That is, the designs shown in Figs. 33, 36, and 38, although they can be used, are not the most desirable for this service. These are the reasons: The values of the unknown resistances which must be determined, in locating faults on power and lighting circuits, are ordinarily quite small. The usual commercial testing set is designed for measuring not only low but also very high resistances. To render a set suitable for measuring high resistances, considerable expensive equipment (high resistance coils and the like) must be incorporated in it. This equipment is seldom if ever used in locating faults on power and lighting circuits (however, it may be used for fault location on telephone and similar relatively high-resistance circuits). Hence, if one, who works only with power and lighting circuits, purchases one of these "high-resistance" sets, he will, in most cases, have tied up in

his outfit a considerable unnecessary investment. For power-and-lighting-circuit trouble location, a simple outfit capable of measuring only low resistances, will ordinarily be found quite satisfactory. Such outfits are shown in Figs. 41 and 44.

40. The Slide-Wire Type Of Wheatstone Bridge is illustrated by the diagram of connections in Fig. 40. The ratio

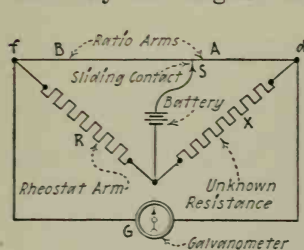


FIG. 40.—Connection diagram of the slide-wire type of Wheatstone bridge.

arms *A* and *B* consist of a single small-diameter high-resistance wire from *d* to *f*. Usually, the rheostat arm, *R*, is so constructed that its resistance may be varied. Instead of the galvanometer, *G*, which is shown in Fig. 40, a telephone receiver is sometimes used to determine when the bridge is balanced. The simple slide-wire bridge is well adapted for localizing faults. Also,

a very practical fault finder which consists of a modification of the slide-wire bridge is described in Sec. 44. For a method of constructing a slide-wire bridge for fault localization see Sec. 45.

41. NOTE.—WHEN A TELEPHONE RECEIVER IS USED TO BALANCE A WHEATSTONE BRIDGE, the resistance in the variable bridge arms is so adjusted that, when the receiver circuit is made and broken, there is no click in the receiver. A click in the receiver indicates that the bridge is unbalanced. Inasmuch as a telephone receiver is sensitive to very small currents, it provides an accurate means of determining when the bridge is balanced. The principal objection to the use of a telephone receiver is that it cannot be determined by the click whether the resistance must be increased or decreased to obtain a balance. Consequently it is seldom used with any of the types of bridges except a slide-wire bridge. Then, the sliding contact *S*, (Fig. 40), is touched at different points along wire *df* until no click is heard. The bridge is then balanced.

42. When Measuring A Resistance With A Slide-Wire Bridge, the bridge is balanced by adjusting arms *A*, *B* and *R*, (Fig. 40), until the galvanometer reads zero, or until the telephone receiver (Sec. 41) does not click. Then, the resistance of *X* is computed by the Wheatstone bridge formula (Sec. 25):

$$X = R \times \left(\frac{A}{B} \right).$$
 If *df* (Fig. 40) is a wire which has a con-

stant cross-sectional area, it is not necessary to know its resistance. The distance in inches (or more conveniently, in centimeters) from S to d may be taken as A , and the distance in inches from S to f may be taken as B . Then, if R is the resistance of the rheostat arm in ohms, X will be the resistance in ohms of the conductor which is being measured. See the following example.

43. EXAMPLE.—In measuring a resistance with a slide-wire bridge (Fig. 40) the bridge is balanced with the following readings: $A = 10.16$ in.; $B = 29.21$ in.; $R = 10$ ohms. What is the resistance of the conductor X ? **SOLUTION:** By the Wheatstone bridge formula above, the resistance of the conductor, $X = R \times \left(\frac{A}{B}\right) = 10 \times (10.16 \div 29.21) = 10 \times 0.347 = 3.47$ ohms.

44. A Home-Made Fault Locator Which Operates On The Slide-Wire Bridge Principle is illustrated in Figs. 41, 42 and 43. It is simple and cheap in construction, and is sufficiently

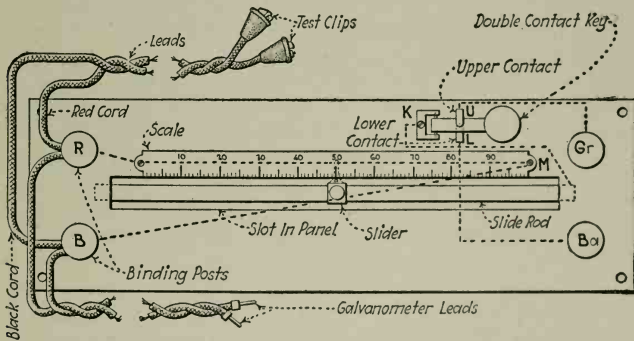


FIG. 41.—Top view of a home-made fault-finder of the slide-wire type. Dotted lines indicate internal connections.

accurate for practical use for circuit-fault locating. An instrument which is constructed as indicated in the illustrations (Figs. 41 and 42) has been used for about a year by a large central station company. During this time it has been used to locate 36 faults in underground cable, with only two false cuts. The error which caused one of these false cuts was a fresh-water ground; the other error was due to an arithmetical mistake in computation. The method of its

use is described in Sec. 42. Its construction is explained below.

45. NOTE.—THE PARTS USED IN CONSTRUCTING THE FAULT LOCATER (Figs. 41, 42 and 43) can be purchased at any radio supply store. The leads, to which the test clips are connected, should consist of equal lengths of No. 14 flexible cord. The cord which connects to binding-post *R* should be red, and the one which connects to post *B* should be black.

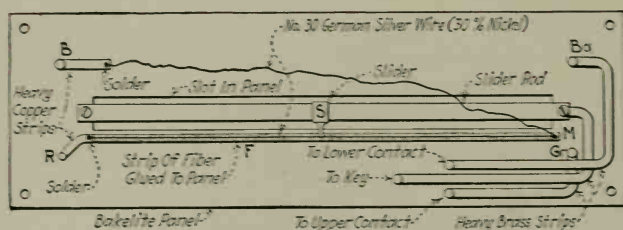


FIG. 42.—Bottom view of the fault-finder panel shown in Fig. 41.

The slider-rod and slider are identical to those which are frequently used on crystal radio receiving sets. The No. 30 German silver wire, *RMB*, should be about 16 in. long. All of the internal connections should be soldered.

It is paramount to the accuracy of the device that the length of wire *RM* be exactly equal to that of *BM*. To insure that these lengths will be equal, first solder the two ends of the 16-in. piece of No. 30 wire to the copper strips at *B* and *R* (Fig. 42), before these strips are mounted on the Bakelite panel. Then hang the wire over a knife edge so that equal lengths of the wire hang on each side. In determining this equal length, only that part of the wire which is not under the solder is considered. Now solder the middle point of the wire to a screw head which has been screwed into the panel at *M*.

Locate the binding post *R* so that the wire *RM* is taut, so that it is parallel to the edge of the slot, and is in the center of the strip of fiber, *F*. The function of this fiber strip, *F*, is to provide a solid backing for the wire so that the tip of the slider *S* can make firm contact with it. The binding-post, *B*, may be so located that the wire *BM* is slack. Locate binding-posts *Ba*, *Gr*, and the double contact key, about as shown.

In the normal position of the key, it contacts with the upper contact, *U*. When it is pressed down, it contacts with *L*. Arrange the slider-rod so that when *S* is moved to the extreme right and left positions (Fig. 42)

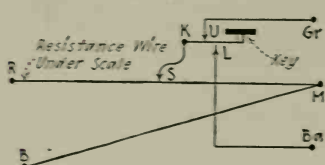


FIG. 43.—Connection diagram of the fault-finder shown in Figs. 41 and 42.

that the tip of the slide will just touch the point where the wire comes out of the solder. The distance between these two points is equal to the total length of the scale. This distance is divided on the scale into 100 equal parts, as shown in Fig. 41.

46. The "L. & N. Power Bridge" (Fig. 44) is a slide-wire bridge which is designed primarily for locating faults in heavy

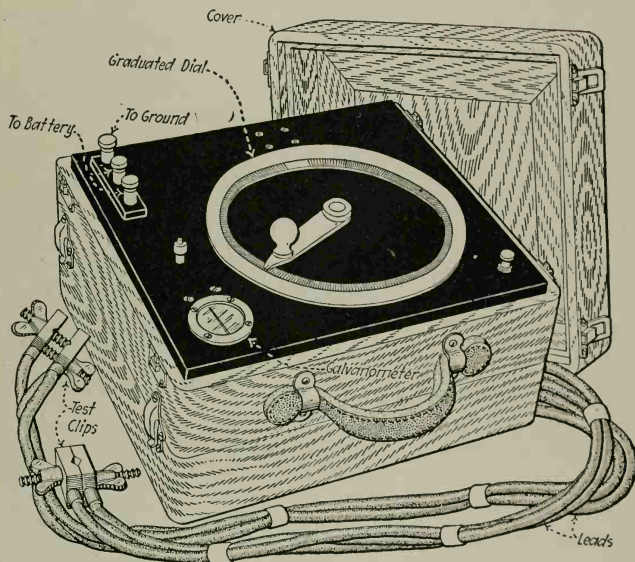


FIG. 44.—The L. & N. power bridge. (*The Leeds & Northrup Co., Philadelphia, Pa.*)

power cables. The diagram of connections is shown in Fig. 45. The low resistance slide wire is mounted upon a circular block inside the case. This wire is of sufficient size to carry 5 amp. continuously. The galvanometer contacts are made at the terminals of the leads. Thus, the resistance leads constitute a part of the slide-wire resistance of the bridge. The scale is divided into 1,000 parts. But to account for the resistance of the two leads, the end divisions are marked 10 and 990. That is, each lead has a resistance which is one forty-ninth that of the slide-wire resistance. With this arrangement, the total slide-wire resistance includes the resistance of the leads. Consequently, no correction for the resistance of the leads

(Sec. 38) is necessary. It will be noted from Fig. 44 that each test clip consists of a pair of heavy copper blocks which are provided with two bolts and wing-nuts. This provides a means of reducing the contact resistance (Sec. 38) to a value which is so small as to be negligible. The method of using this instrument is explained in Sec. 153.

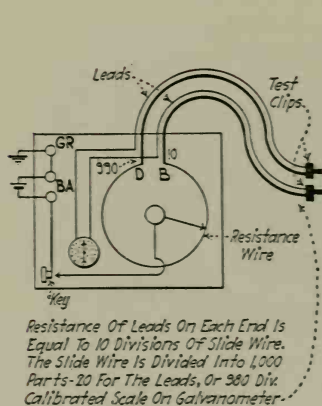


FIG. 45.—Diagram of connections of the power-bridge fault-finder shown in Fig. 44.

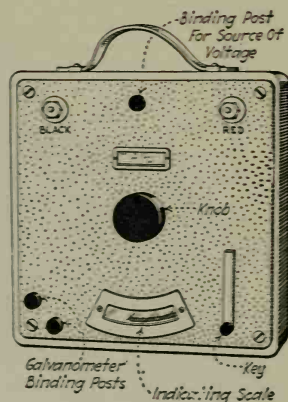


FIG. 46.—A portable fault localizer. (The Westinghouse Electric & Mfg. Co.)

47. NOTE.—THE “WESTINGHOUSE PORTABLE FAULT LOCALIZER” is illustrated in Fig. 46. The location of a fault with this instrument is read off from the dial directly in per cent of the total length of the line. Its method of use and principle of operation are explained in Sec. 121.

48. The Devices Or Instruments Which Are Employed In Locating Faults In Electric Conductors By The “Tone Test” consist of an apparatus for producing a varying current in the faulty conductor, and an apparatus for detecting the existence of this current. The varying current may be alternating-current, pulsating direct-current, or a combination of both. The apparatus that is used for detecting the existence of the current comprises some sort of an exploring coil which is connected to a telephone receiver or to a sensitive voltmeter. For a description of certain commercial types of such devices see the following sections.

49. The Matthews “Telefault” (Fig. 47) one popular form of “tone-test” instrument, contains an induction coil, a dry-

cell, and the necessary wiring (Fig. 48) inside a wooden case. The induction coil (*I*) consists of a primary and a secondary winding on a laminated iron core. The dry-cell battery is

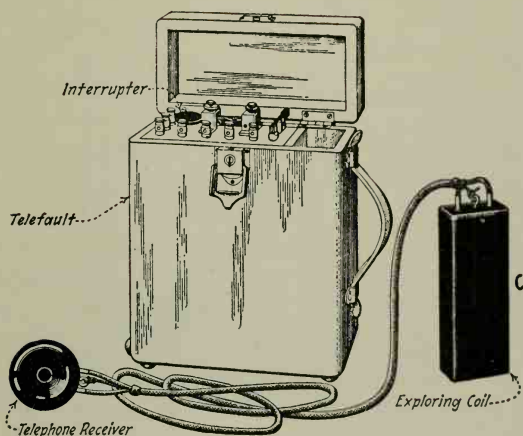


FIG. 47.—The Matthews Telefault. (W. N. Matthews & Bro., St. Louis, Mo.)

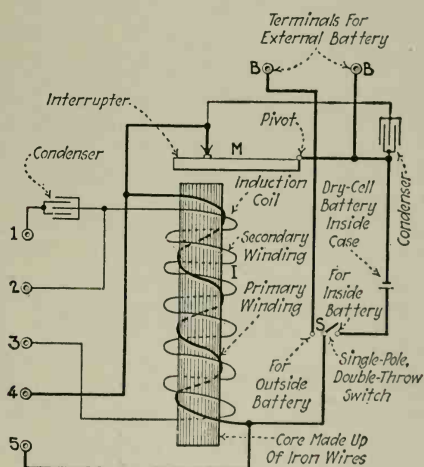


FIG. 48.—Wiring diagram of the Matthews Telefault.

connected to the primary winding of the coil through a contactor, *M*. When the switch is closed, the vibration of the contactor makes and breaks the primary current. This

induces a relatively high voltage on the secondary. The secondary and primary windings are connected to suitable terminals (1, 2, 3, 4, and 5) on the outside of the case. The

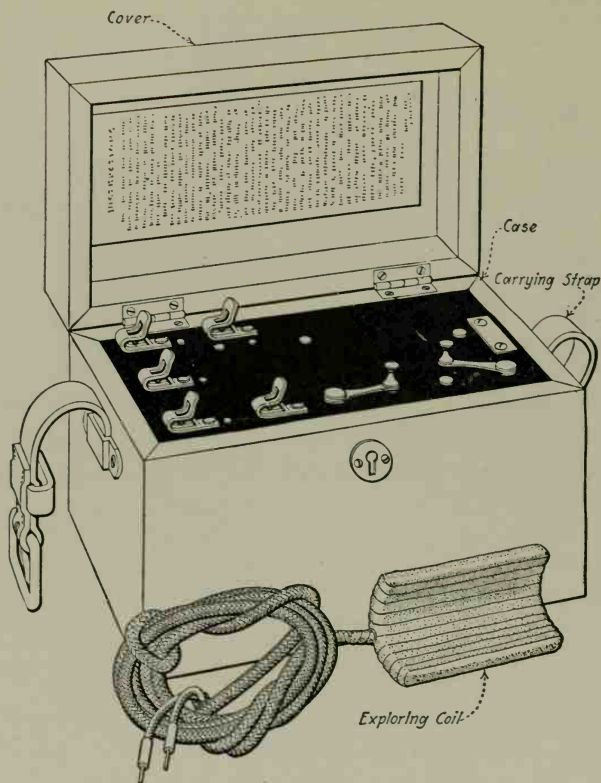


FIG. 49.—Exterior view of the "Queen Wireless Test Set." (Queen-Gray Co., Philadelphia, Pa.)

two terminals, *B* and *B*, are for connecting an outside battery to the apparatus when a strong signal is necessary. The method of operation is explained in Secs. 161 and 162.

50. The "Queen Wireless Test Set" (Figs. 49 and 50), another "tone test" device, contains a buzzer which is connected to the primary winding of an induction coil. Thus, the make and break of the current from the battery by the buzzer induces a relatively high pulsating voltage in the secondary

winding of the induction coil. This high voltage is used to send a current through the fault. See Sec. 163 for instructions concerning its use.

51. The Lundin Fault Locator (Fig. 51) is probably the most elaborate device manufactured commercially for locating trouble on electric power lines. It consists of an analyzer, a motor-driven interrupter, and one or more lighting transformers. The function of the analyzer is for indicating what kind of a fault has occurred, to reduce its resistance (Sec. 99), and also to obtain some idea of the nature and probable location of the fault. The interrupter is used to send a "tone test" signalling current over the faulty conductor. The position of the fault is located by an exploring coil and telephone receivers. Exploring coils of various types

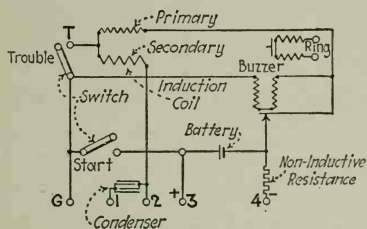


FIG. 50.—Wiring diagram of the "Queen Wireless Test Set" shown in Fig. 49.

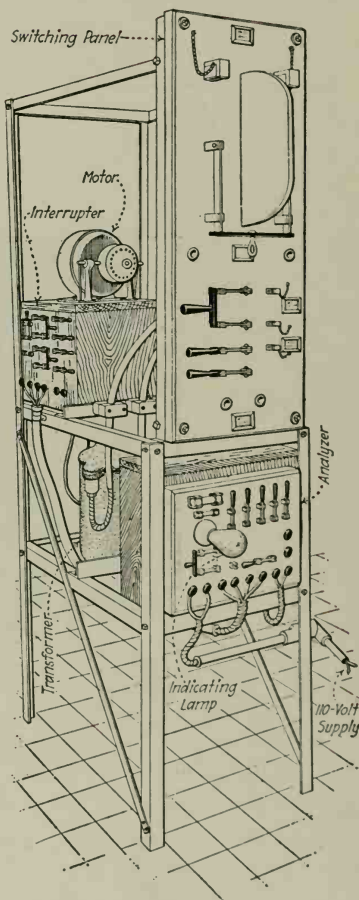


FIG. 51.—The Lundin Fault Locator set up for station use in circuit testing and fault location. (*The Lundin Electric & Machine Co., Boston, Mass.*)

and also telephone receivers constitute a portion of the standard equipment which is supplied with the apparatus by the manufacturer. This apparatus is used by a large

number of power and lighting central station companies. When properly operated it is very accurate in locating nearly any kind of a fault. A number of the uses of this apparatus, as stated by the manufacturer, are recited in Sec. 164.

52. The Lundin Amplifier Is A Device Used To Amplify Signals Obtained In A Telephone Receiver When Locating Faults On A Line.—This device (Fig. 52) magnifies the signals

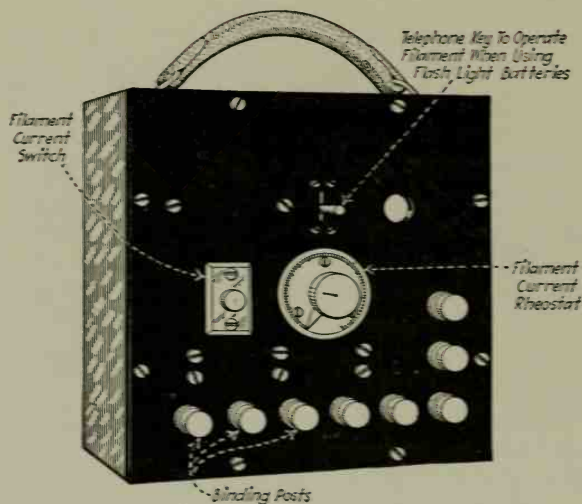


FIG. 52.—Outside view of the Lundin amplifier. It is a device used to amplify the signals when locating faults. (Manufactured by the Lundin Electric & Machine Co., Boston, Mass.)

on the line (made by the interrupter) about three times. The amplifier operates on the same principle as an audio-frequency amplifier used in a radio receiver. The amplifier consists of a vacuum tube, filament rheostat, filament battery, plate battery, switches and the necessary binding posts for making the connections. Provisions are made to operate the filament of the vacuum tube from a storage battery when such is available. However, dry-cells (flashlight batteries) are ordinarily employed with the instrument. A telephone switch-key is provided for controlling the filament current when it is supplied from the flashlight batteries which are furnished with the amplifier.

53. Several Types Of Exploring Coils Are Used in locating faults by the "tone-test" method. The principal iron-core types are: (1) *Bar* (Fig. 53). (2) *Sector* (Fig. 54). (3) *U-shaped* (Fig. 55). Exploring coils which have air cones are usually circular (Fig. 56) or triangular (Fig. 57).

54. As To The Winding Of Exploring Coils, definite information cannot be given concerning the number of turns of wire

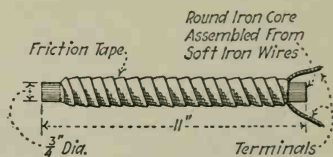


FIG. 53.—Exploring coil of the bar type.

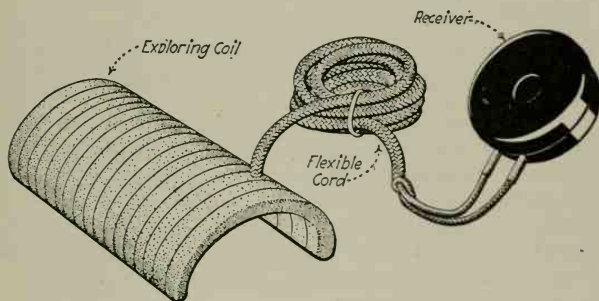


FIG. 54.—A sector type of exploring coil.

which should be used on an exploring coil. The impedance of the coil should, for best results, be equal to that of the

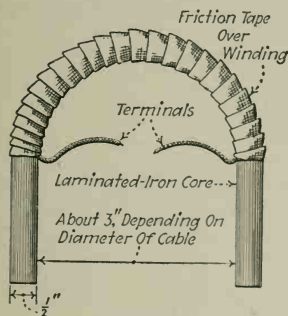


FIG. 55.—U-shaped exploring coil.

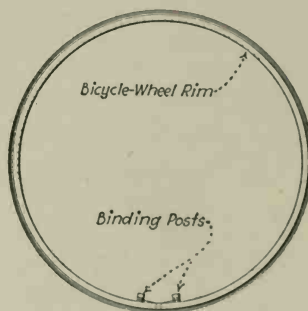


FIG. 56.—Exploring coil made by winding 5,000 turns of No. 36 enameled copper wire on a bicycle-wheel rim.

receiver with which it is used. The ohmic resistance of receivers varies from about 75 ohms, in receivers of the type

used in wire telephony, to 2,000 or 3,000 ohms in those which are used in radio telephony. The number of turns of wire for

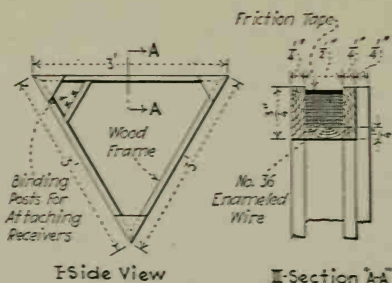


FIG. 57.—A triangular exploring coil.

an exploring coil of the iron-core type usually varies from about 600 or 700 to 2,000 or 2,500 turns. Exploring coils of the air-core type (Fig. 56) may have as many as 5,000 turns. Ordinarily, wire (single cotton-covered or enameled) smaller than No. 36 or larger than No. 26 should not be used.

55. NOTE.—THE EXPLORING COIL WHICH IS FURNISHED WITH THE TELEFAULT (Sec. 161) is shown in Fig. 58. This coil consists of two windings on the same core, each of which consists of 350 turns of No. 28 wire. One winding (Fig. 59) is connected to the telephone receiver. The other winding is connected to the two terminals of a condenser. This arrangement, so the manufacturer states, materially increases the volume of sound in the receivers.

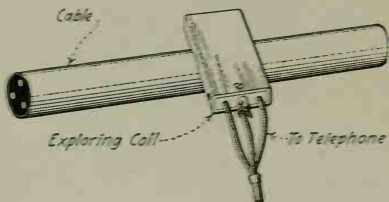


FIG. 58.—Showing the correct position of the Matthews Telefault exploring coil on the cable.

56. NOTE.—EXPLORING COILS OF SPECIAL TYPES are described in Div. 2 in connection with the explanation of their operation.

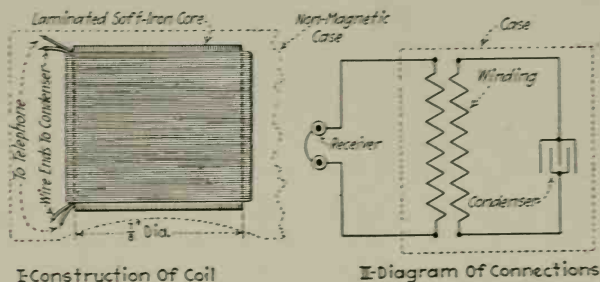


FIG. 59.—Illustrating arrangement of the exploring coil of a Matthews Telefault.

57. The "Shortfinder" Is A Combination Frequency Tester, Current Detector, Slot Explorer, Polarity Indicator And Compass.—Figure 60 illustrates a Shortfinder, its dimensions being approximately those of an ordinary fountain pen.

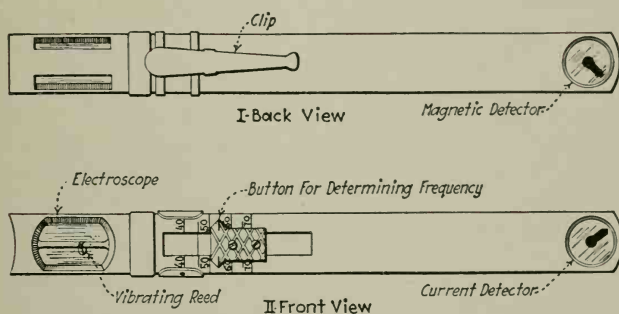


FIG. 60.—Diagram of a "Shortfinder" manufactured by the *Eisenmann Shortfinder Co.*, Nebraska City, Nebraska.

58. EXPLANATION.—On one end of the instrument a compass is provided. Upon opposite ends of the staff of the compass, two non-magnetic pointers are attached; one shows on each face of the instrument.

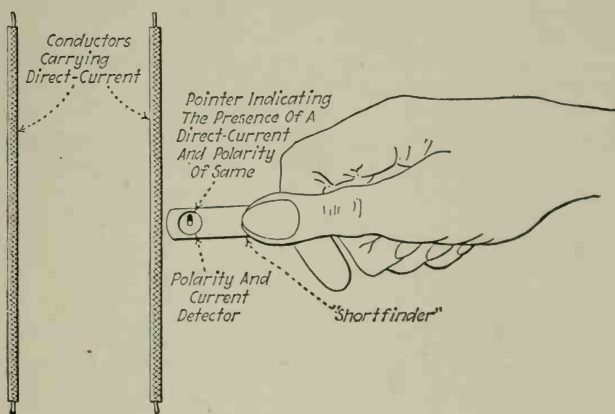


FIG. 61.—"Shortfinder" used as a current detector and polarity indicator on a direct-current circuit.

One is in the direction of the North Magnetic pole of the compass needle. This pointer indicates direction of magnetic flux of a direct current. The other pointer is set, at right angles to the compass needle,

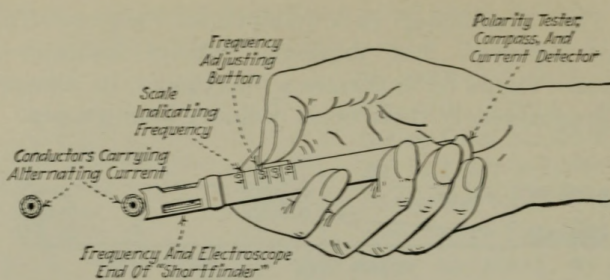


FIG. 62.—"Shortfinder" used as a frequency tester.

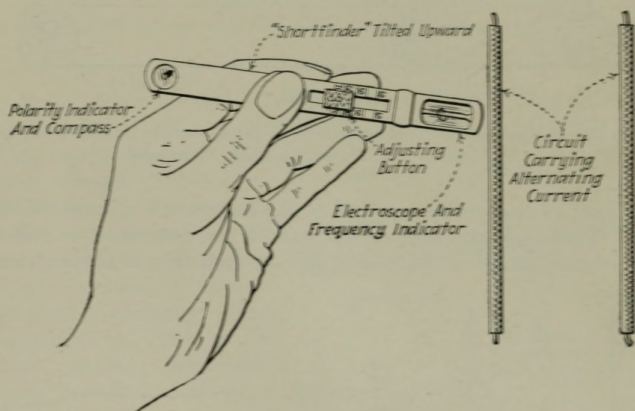


FIG. 63.—"Shortfinder" used as a current detector on an alternating-current circuit.

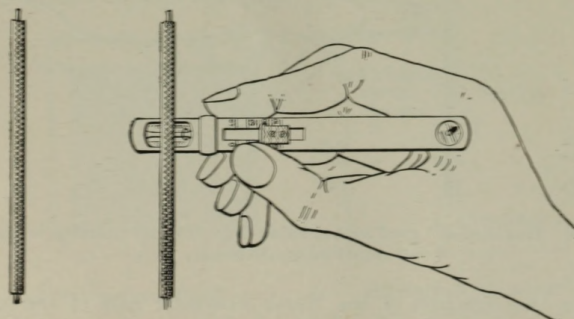


FIG. 64.—"Shortfinder" used as an electrostatic detector to detect the presence of voltage.

in such a direction that it will constitute a polarity indicator and (Fig. 61), when held near a conductor through which a direct current is flowing, indicate the direction of current.

On the other end of the instrument, enclosed in a glass tube, are a frequency indicator and an electroscope. The frequency indicator (for determining the frequency of an alternating current, Fig. 62) is a tuned-reed device operating on the resonance principle. An adjusting button is provided to tune the reed to the frequency of the current being tested. This device also serves as a current detector (Fig. 63) on alternating-current circuits which have a frequency within the range of the instrument.

The electroscope is used (Fig. 64) for determining the presence of voltage on circuits in which there is no current. The electroscope consists of a small very light metal ring which is so placed that it is free to move along the reed. To use the electroscope hold the instrument with the glass window of the electroscope downward and place it over and at right angles to the wire so that the middle of the glass window is over the wire. The instrument is then slowly tipped so that the ring will slide to the other end of the reed. If the ring slides freely to the other end of the reed, the wire is not "live." The wire should not be carrying any current during this test. If, however, the ring will catch or stick about midway down or when it is opposite or nearest the wire, then there is voltage impressed on the wire. The application of this device for locating various troubles in electric circuits are explained in Div. 3. The "Slot explorer" feature utilizes the frequency-indicator element for armature-winding testing.

59. NOTE.—THE SENSITIVENESS OF THE "SHORTFINDER" for its different applications is about as follows: The polarity indicator pointer will show the direction of $\frac{1}{2}$ ampere direct current when held within $\frac{1}{2}$ in. of the conductor. The frequency indicator will indicate a $\frac{1}{2}$ ampere alternating current, when held $\frac{1}{2}$ in. away from the conductor. The electroscope will indicate the presence of 100, or more, volts through the insulation on a conductor. The shortfinder cannot be used on outside of conduit for testing conductors which are inside of a conduit due to the iron short-circuiting the magnetic flux. When the device is used for testing conduit wiring the tests must be made at an outlet or junction box where the conductors are accessible.

60. Instruments Which Are Designed Primarily For Measuring High Resistances are the Megger (Fig. 65) and Megohmer (Fig. 66). The application of both of these devices, is substantially the same. The operating principle of the Megger and that of the Two-In-One Megohmer are described in detail below. Instruments of this type are employed principally for the measurement of insulation resistance, as is explained in Div. 5.

61. The "Megger Testing Set" consists principally of a direct-reading ohmmeter and a hand-driven direct-current generator compactly assembled in one portable box. The

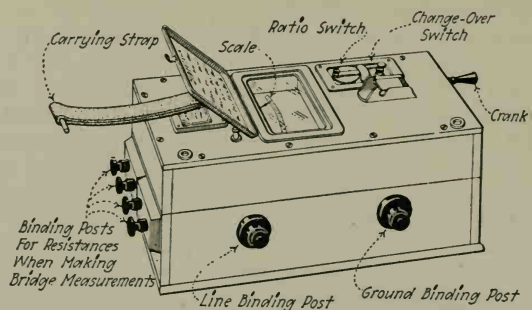


FIG. 65.—General view of the Bridge Megger testing set manufactured by James G. Biddle, 1211-13 Arch Street, Philadelphia.

Meggers are made in a number of different capacities with ranges of from 0 to 5 megohms up to 4 to 10,000 megohms. The voltage developed by the hand-driven generator depends

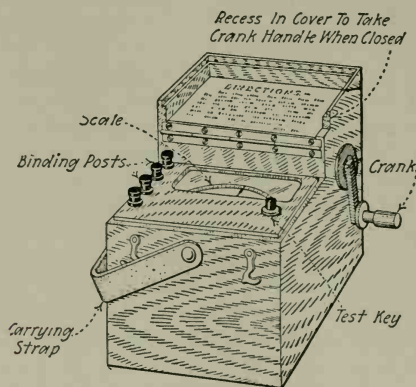


FIG. 66.—Diagram showing Model D Standco Megohmer ready for use. The generator crank is of the folding type and fits into a recess in the cover of the instrument. The binding posts are so mounted that they are protected when the cover is closed. Full operating instructions are mounted in the cover of the instrument. (Herman H. Sticht and Co., New York, Bull. No. 115.)

upon the range of the instrument of which it constitutes a part. For a range of 0 to 5 megohms, the generator pressure is 500 volts, while for a range of from 4 to 10,000 megohms the

generator pressure is 2,500 volts. Each instrument reads directly in megohms.

62. NOTE.—A MEGOHM is a unit of resistance which is equal to one million (1,000,000) ohms. Thus the full scale reading of an instrument which has a range of 5 megohms is 5,000,000 ohms.

63. The Operating Principle Of The Megger is briefly this: a voltage generated by the hand-driven generator forces a current through a divided circuit of two paths. In both paths are connected coils suitably mounted on a magnetically

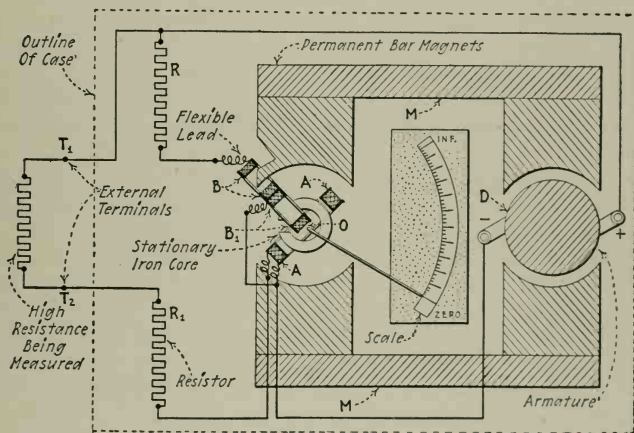


FIG. 67.—Diagram of Megger testing set showing principal magnetic circuit and electrical connections. (James G. Biddle, 1211-13 Arch Street, Philadelphia, Pa.)

actuated rotating element to which a pointer is attached, and which moves over a scale which is calibrated in ohms and megohms. When the terminals of the Megger are connected to a high resistance, and the generator crank is turned, the proportion of the currents which flow through the differentially-wound coils on the movable element determine the deflection of its pointer. The scale over which the pointer moves is calibrated to indicate the resistance of the circuit which is connected in the Megger terminals. Any variation of the voltage generated by the hand-driven generator or the changing of the strength of the permanent magnets does not effect the accuracy of the instrument. See explanation below.

64. EXPLANATION.—A clear understanding of the operation of the set can best be obtained by carefully considering the diagram, Fig. 67 (see also Fig. 201), which shows the essential magnetic circuit and electrical connections. *MM* are permanent bar magnets. Between their poles at one end, is the armature *D* of the hand-driven direct-current generator. Between the poles at the other end, is the moving system of the ohmmeter. The latter has three coils, *A*, *B* and *B'* (Fig. 67) rigidly fixed together, and freely rotating about the axis *O*, without the directive influence of any controlling springs.

If there is nothing connected across the external terminals, T_1 and T_2 , and the generator is operated at proper speed by the small crank at the right-hand end of the set, as shown in Fig. 65, current will flow only through the two coils *B* and *B'* connected in series. The electrical reaction thus set up drives these coils to a position where minimum flux from the permanent magnet passes through them; that is, to directly opposite the gap in the C-shaped iron piece about which the coils *A* and *B* move. The pointer then stands over the line marked "Infinity" on the scale.

If now a suitable high resistance is connected to T_1 and T_2 , the current from the generator has two paths open to it and will divide, part passing through coils *B* and *B'* and part through coil *A*, which is in series with the resistance under test. The result is that the current in coil *A* exerts a deflecting torque toward the position shown in Fig. 201, and opposed to that produced by coils *B* and *B'*. As the system moves, the coils *B* and *B'* offer an increasingly strong restraining torque until the turning force due to coil *A* is balanced and the pointer comes to rest at a location on the calibrated scale which correctly indicates the value of the resistance which is connected between the external terminals. Should these terminals become short-circuited, no harm is done to the instrument; the coil *A* simply overpowers the coils *B* and *B'* and the pointer is moved to the lowest point on the scale. Each circuit in the instrument has in it a suitable resistor, as indicated in Fig. 201, for properly protecting the sensitive parts from injurious overloads.

65. The Meggers Are Made In Three Types: (1) *Variable-Pressure Testing Sets* (2) *Constant-Pressure Megger Testing Sets* (3) *Constant-Pressure Bridge Megger Testing Sets*.—In the Variable-Pressure Sets (see author's "Wiring For Light and Power" and "Conduit Wiring" for illustrations) the voltage which is developed by the hand-operated generator varies with the speed at which the crank is turned. In the Constant-Pressure Sets the generated voltage is, by means of a specially designed clutch, maintained constant, regardless of the speed at which the crank is turned, provided this speed exceeds 100 r.p.m. In the Constant-Pressure Bridge Megger Set

additional equipment is installed whereby the outfit can, in addition to being used as a Megger, be employed for the services to which an ordinary Wheatstone bridge is applicable. When thus used as a bridge, it will measure resistances as low as 0.001 ohm and as high as 1 megohm. It can be used for making the Varley-loop and Murray-loop tests as described in Div. 2. When one of the Bridge-Type Meggers is used in a Wheatstone-bridge test, an auxiliary resistance box must be employed as shown in Fig. 68.

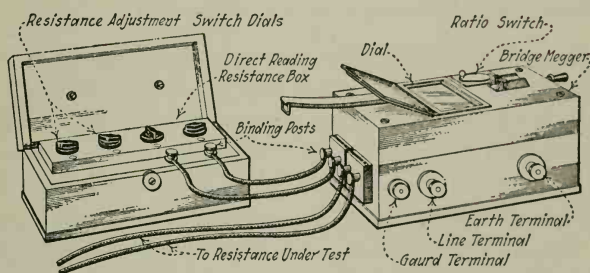


FIG. 68.—Bridge "Megger" used as a Wheatstone bridge.

66. NOTE.—THE APPLICATION OF THE MEGGERS OF THE DIFFERENT TYPES are, in general, these: The Variable-Pressure Megger Sets are suitable for measuring insulation resistance of wiring installations, elec-

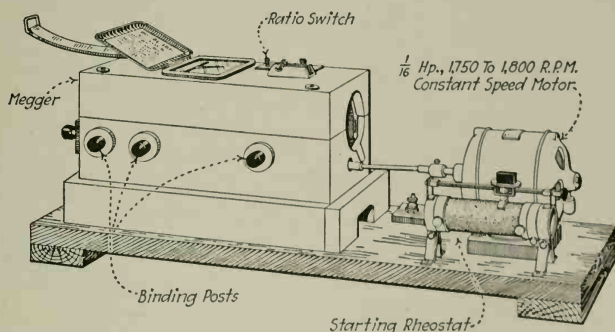


FIG. 69.—Illustrating a motor-driven Megger testing set. (Manufactured by James G. Biddle, 1211-13 Arch St., Philadelphia, Pa.)

trical equipment and electrical machinery, where the electrostatic capacity (capacitance) to ground does not exceed 1 mf. (microfarad). These sets are built in ranges of from 0 up to 100 megohms. The Constant-Pressure Megger Testing Sets (which are built in ranges of from 0

up to 10,000 megohms) are suitable for measuring insulation resistance of all electric circuits, apparatus, and devices of the usual operating voltages, that is up to 600 volts. Thus the Constant-Pressure Sets should be employed for measuring the insulation resistance of all medium and large capacity electrical machines, transformers, high-tension cables and feeders, high-tension insulators, telephone cables, railway signal circuits and extensive wiring installations. The Constant-Pressure Bridge Megger Sets may be employed for all of the services above specified for the Constant-Pressure Sets and in addition for those testing applications in which an ordinary Wheatstone bridge is ordinarily used. Where considerable testing is to be done in one location, a constant-speed motor (Fig. 69) may be arranged to drive the Megger.

67. The "Meg" (Figs. 70 and 71) is a compact self-contained instrument which operates by virtue of the same principle as that which is employed in the Megger and which has been previously explained. It is made in only one capacity, 0 to 100 megohms. The general instructions which are given in Div. 5 for the use of the Megger also apply for this instrument. Its generator is of the variable-pressure type. It

cannot be equipped with the "Bridge" feature. Its price is about \$200. Its dimensions are $5\frac{1}{2} \times 7\frac{3}{4} \times 6\frac{1}{4}$ in. and its weight is $6\frac{3}{4}$ lb.

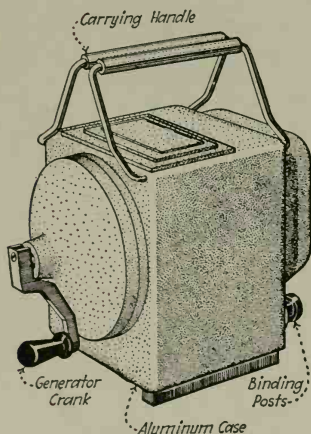


FIG. 70.—The *Meg* insulation tester. (James G. Biddle, 1211-13 Arch Street, Philadelphia, Pa.)

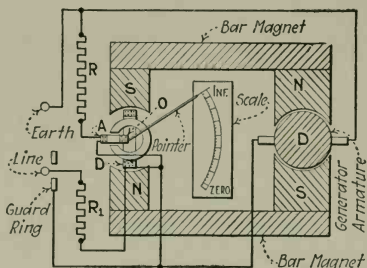


FIG. 71.—Diagram of the internal connections of the "Meg" insulation tester. (James G. Biddle *Pocket Manual* 1,010.)

68. NOTE.—THE APPLICATION OF THE MEG is for measuring high resistance—principally insulation resistance—of electrical circuits and apparatus, where the resistance to be measured does not exceed 100 megohms and the electrostatic capacity between the circuit being

measured and ground does not exceed 0.5 mf. For accurate results on circuits which have a capacitance to ground in excess of 0.5 mf. a generator of the constant-pressure type is necessary. Hence for such services a Megger (hereinbefore described) which is equipped with a constant-pressure generator should be employed. The fact that the Meg is inaccurate on circuits which have high capacitance renders it unsuitable for measuring the insulation resistance of long feeder cables, telephone cables and large capacity electrical machinery. It is entirely satisfactory for testing wiring installations in buildings and industrial plants and the electrical machinery which is handled in the ordinary repair shop.

69. NOTE.—THE PRICE RANGE OF THE MEGGERS OF THE DIFFERENT TYPES are approximately as follows:

Variable-Pressure Megger Testing Sets \$180.

Constant-Pressure Megger Testing Sets from \$304 to \$600

Constant-Pressure Bridge-Megger Testing Sets from \$600 to \$800.

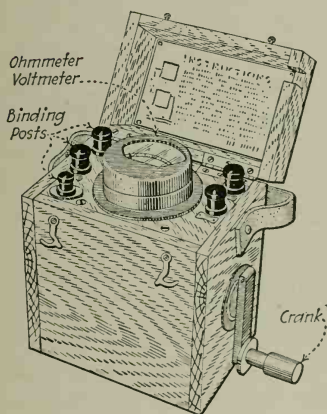


FIG. 72.

FIG. 72.—The "Junior" Megohmer, designed to measure megohms and volts. (Herman H. Sticht & Co., New York, Bull., No. 125.)

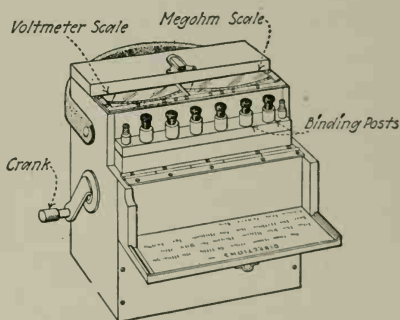


FIG. 73.

FIG. 73.—Diagram of the "2 in 1" Megohmer designed to measure megohms or volts. The instrument has a differential galvanometer movement with megohm and ohm scales, a hand-operated magneto generator and a voltmeter for alternating-current and direct-current measurements. (Herman H. Sticht & Co., New York, Bull. No. 115.)

70. The Megohmers Are Manufactured In Three Styles:

(1) The "Junior" Megohmer (Fig. 72). (2) The Model "D" Megohmer (Fig. 66). (3) The "2 in 1" Megohmer (Fig. 73). The "Junior" Megohmer is designed for making insulation resistance measurements where relative values, quickly obtainable are of more importance than very accurate determina-

tions. It is particularly recommended for maintenance work on telegraph, telephone and signal systems. It has a range of from 0 to 20 megohms, and in addition two direct-current voltmeter ranges, 0 to 120 and 0 to 240 volts. It is equipped with a hand-driven generator, which develops 110 volts, pulsating direct current, at about 180 r.p.m. of the crank. The movement of its indicating element is of the D'Arsonval galvanometer type and is dead heat. Its dimensions are $3\frac{5}{8} \times 5\frac{1}{4} \times 6\frac{3}{4}$ in. and its weight is $4\frac{3}{4}$ lb. Its price is \$62.50. The Model "D" Megohmer (Fig. 66) is of the same general design as the Junior type, with the exception that it is more suitable for tests where greater accuracy is desired. It has the same type of movements. Its generator is designed to produce 220 volts, pulsating direct current, for a megohm range of 0 to 20 megohms and 440 volts for the 0- to 40-megohm range instrument. It also has a direct-current voltmeter range of 0 to 120 and 0 to 240 volts. The price for the 0- to 20-megohm model is about \$90 and for the 0- to 40-megohm range is about \$115.

71. The Operating Principle Of The Model "D" Megohmer

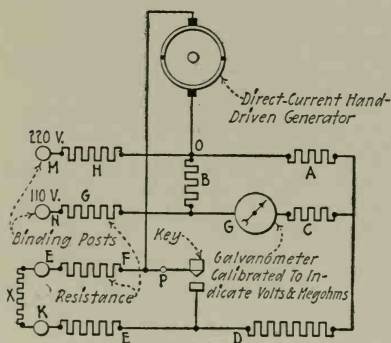


FIG. 74.—Diagram showing the internal connections of the Model "D" Megohmer. (Herman H. Sticht & Co., New York, N. Y., Bull., No. 115.)

(Fig. 66) is briefly this: When an unknown high resistance X (Fig. 74) is connected to terminals marked E and K of the megohmer, an external path is provided for the current which is forced through the circuit by the generator voltage. A galvanometer, G (which has a D'Arsonval-type movement) is in the circuit

of the unknown resistance, and its scale is calibrated so that its pointer will indicate the resistance of the circuit under measurement. Resistances A , B and C serve as calibrating resistances, as does D , while resistances E and F serve to protect against short-circuit, should the key P be

pressed when the terminals *E* and *K* are connected to a live line. Resistances, *A*, *B* and *C* are so proportioned that the ohm scale of the instrument applies not only for measurements with the generator voltage but also for measurements made with 110 and 220 volts obtained from an outside source of voltage and connected respectively to *N*, *K* and *M*, *K*.

72. NOTE.—THE OPERATING PRINCIPLE OF THE JUNIOR MEGOHMER (Fig. 72) is essentially the same as that of the Model "D" Megohmer. Figure 75 illustrates the internal connections of this model, showing the calibrating resistances, protective resistors, galvanometer, shorting key and generator connections. The reference letters on Fig. 75 correspond to those on Fig. 74.

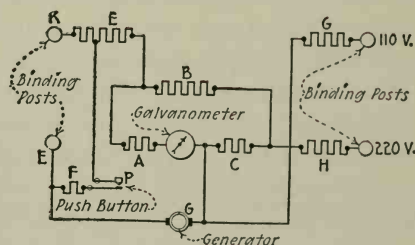


FIG. 75.—Diagram of internal connections of the Junior Megohmer. (Herman H. Sticht & Co., Bull. No. 125.)

73. The "2 in 1" Megohmer Is Designed For Making Measurements Of Greater Accuracy Than Can Be Obtained With The Model "D,"

Megohmer. The manufacturer recommends this type (Figs. 73 and 76) when the accuracy of a precision instrument is desired. The movement in this type of Megohmer is of the differential galvanometer type, with both megohm and ohm scales.

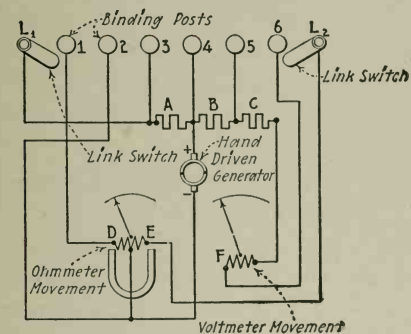


FIG. 76.—Diagram showing the internal connections of the "2 in 1" Megohmer shown in Fig. 73. (Herman H. Sticht and Co., New York Bull. No. 115.)

The generator is of the hand-operated magneto type. The instrument is also equipped with a voltmeter, suitable for measuring both alternating and direct current. The generator furnishes a practically uniform direct current at 250 volts for the 0- to 25-megohm range, 500 volts for the 0- to 50-megohm range and

1,000 volts for the 0- to 100-megohm range. The voltmeter ranges are 0 to 110 volts and 0 to 220 volts for both the 0- to 25- and the 0- to 50-megohm-range types. For the 0- to 100-megohm-range type, the voltage ranges are 0 to 120 volts and 0 to 240 volts. A new model has been designed having a 0- to 600-volt and a 0- to 1,200-volt voltmeter range. The "2 in 1" Megohmer is also equipped with a 0- to 5,000-ohm scale and is therefore suitable for measuring the resistance of field windings and other resistances which come under that range. The prices of the "2 in 1" Megohmer are about \$220 for the 0- to 25-megohm range, \$240 for the 0- to 50-megohm range and \$260 for the 0- to 100-megohm range.

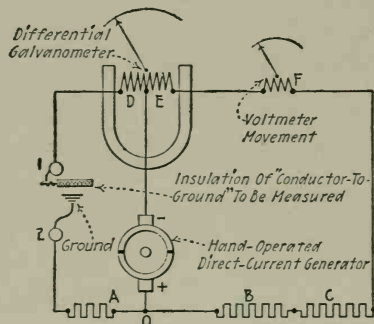


FIG. 77.—Schematic diagram of the internal connections of the "2 in 1" Megohmer connected to a circuit for measuring its insulation resistance to ground.

74. The Operating Principle Of The "2 in 1" Megohmer (Fig. 77) is as follows: The resistance measuring system is of the differential galvanometer type consisting of two coils *D* and *E*, mounted on a common shaft as shown in internal wiring diagram (Fig. 77). Coil *D* is the series coil and is energized by the current leaking through the insulation resistance under measurement. The coil *E* is connected in parallel with the generator through the voltmeter *F* and suitable resistances *B* and *C*. The two coils *D* and *E* are wound in opposite directions, so that when they are energized from the generator, they tend to move the pointer in opposite directions. The torque produced by the coil *D* varies with the current through the resistance being measured; the torque produced by coil *E*

varies with the potential of the generator. The deflection of the pointer therefore, varies as the voltage divided by the current or as $E \div I$. The resultant readings are therefore independent of the generator voltage. When link switch L_2 (Fig. 76) is closed, the voltmeter measures the generator voltage. With link switch L_2 open, the voltmeter can be used as any ordinary portable voltmeter. The application of the Megohmer is explained in Secs. 302 to 305.

QUESTIONS ON DIVISION 1

1. What is the underlying principle upon which all testing of circuits for faults is based?

2. What should be done when it is necessary to know the resistance of each instrument lead?

3. Why should fuses be tested when they are installed?

4. Make sketches of several different fuse-testing devices and explain the operation of each.

5. What is a lamp-testing device? Make a sketch of a lamp-testing device.

6. What is a test lamp?

7. What must be considered in assembling a test-lamp set?

8. What is a battery-test set? Make a sketch of three battery-test sets showing the construction and wiring.

9. What is a magneto-test set? What precautions should be observed in testing a circuit with a magneto?

10. What is a Wheatstone bridge?

11. Make a schematic circuit diagram of a Wheatstone bridge.

12. Derive the Wheatstone bridge formula.

13. Name and describe the three principal types of commercial Wheatstone bridges. What are the advantages and disadvantages of each? Explain in detail the method of measuring a resistance with a Wheatstone bridge of each of the above types.

14. Make a diagram of a slide-wire Wheatstone bridge. Explain how to measure a resistance with it.

15. Describe the method of constructing a fault locator on the slide-wire bridge principle. Make a sketch.

16. Make a sketch showing the connections of the "L and N Power Bridge." What are some of the features of this type of bridge?

17. Name the instruments which are usually employed in locating faults in electric conductors by the "Tone Test."

18. Explain the method of locating a fault in a conductor by the "Tone-Test" method.

19. Name several instruments, which are manufactured, that employ the "Tone-Test" principle for the locating of faults in electric conductors

20. Describe the Matthews "Telefault," using sketch to illustrate.
21. Explain the operation of the "Queen Wireless Test Set."
22. Give a brief description of the "Lundin Fault Locator." Explain the function of the various parts of the "Lundin Fault Locator."
23. Upon what principle does the "Lundin Amplifier" operate? For what purpose is the "Lundin Amplifier" adapted?
24. Make a diagram of several types of exploring coils used in locating faults by the "Tone-Test" method.
25. Name several uses for the "Shortfinder."
26. Give a brief description of the "Shortfinder" using a diagram.
27. Show the method of using the "Shortfinder" to determine the frequency of an alternating current. Show the method of detecting the presence of a voltage on a conductor, with the "Shortfinder."
28. Name and describe several of the instruments which are designed primarily for measuring high resistances.
29. In what units of resistance are these instruments usually calibrated?
30. Give a brief description of the operating principle of the "Megger" testing set.
31. Name the several types of "Megger" which are now being manufactured, giving a brief description of each.
32. What are the applications of the various types of "Meggers?"
33. Give a brief description of the "Megohmer." Name the three styles in which the "Megohmer" is manufactured and give the application of each style.

DIVISION 2

LOCATING FAULTS IN MULTIPLE TRANSMISSION AND DISTRIBUTION CIRCUITS

75. Those Faults Which Occur Frequently In Any Electric Circuit are: (1) *Ground*, wherein one or more conductors of a circuit accidentally come in contact with "earth." (2) *Short-circuit*, wherein two or more conductors of a circuit come in contact with each other. (3) *Open-circuit*, wherein one or more conductors of a circuit are accidentally broken and separated, thereby interposing a sufficiently high resistance into the circuit to prevent the flow of an appreciable electric current. (4) *The simultaneous occurrence of any two, or of all three of these faults*. In this division various methods of locating these faults on underground and overhead transmission and distribution circuits are described. Then, in Divs. 3 and 4 different means of locating these same faults on *multiple interior wiring systems* and on *series-lighting circuits* are described.

76. NOTE.—BY "MULTIPLE TRANSMISSION AND DISTRIBUTION CIRCUITS" IS HEREIN MEANT those circuits which are utilized for the transmission of electrical energy from a central station to various substations, from substations to substations, and from substations to the consumers service entrances which are scattered over a relatively large area. The reason why the methods which are employed in locating faults in such multiple circuits and in multiple interior circuits differ is principally due to the difference in length and accessibility of the circuits of these two classifications.

77. The Four Methods Which Are Most Frequently Used In Locating Faults In Transmission Lines are: (1) *Sectionalizing*. (2) *Electrical measurements*. (3) *Tone tests*. (4) *Patrolling*. When a fault occurs it is of course highly desirable that it be located, repaired, and the faulty line placed in service in minimum time. Which of the above methods will produce this result will depend upon certain conditions. A judicious

selection of the proper method can only be made by one who has a thorough knowledge of the wiring system and of the limitations of each method. These conditions and limitations are described hereinafter in this division.

78. A Map Of The Wiring System Is Essential In The Location Of Faults.—This is especially true for large systems, since in a large system it is practically impossible for a person to memorize the necessary information. The minimum information which such a map should contain is the location and numbering of all primary conductors and their sizes, the location of all disconnect switches, transformers, and other equipment therein. This map is in the possession of whoever directs the locating of faults, such as the load dispatcher or the head of the trouble department. Thus, this person may direct the "trouble man" to go to a definite location and do certain things. When the trouble men have done this, they so report. Then the person who is directing the location of trouble, communicates certain instructions to the station operator. In this manner, the fault can be located with the least possible service interruption and maximum safety.

79. How An Accidental Ground Manifests Itself depends upon whether or not the circuit upon which it occurs is perma-

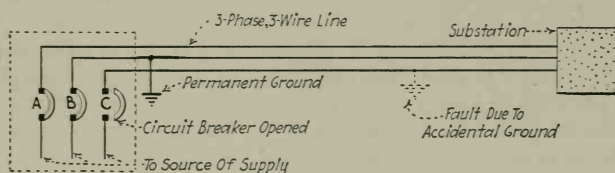


FIG. 78.—Accidental ground on a permanently grounded system which causes circuit-breaker, C, to open.

nently grounded. If one of the conductors of the circuit is permanently grounded, an accidental ground will ordinarily manifest itself (Fig. 78) by the opening of a circuit-breaker or the blowing of a fuse. If the circuit is not permanently grounded, it should be equipped with suitable ground detectors. In this event an accidental ground will cause the ground detector (Fig. 79) to function, and the fault can sometimes be located (Sec. 77) and removed without an interruption of

service. If an accidental ground on such a permanently ungrounded system is not immediately removed, sooner or later another conductor of the circuit will become accidentally grounded (Sec. 231), thus producing a short-circuit.

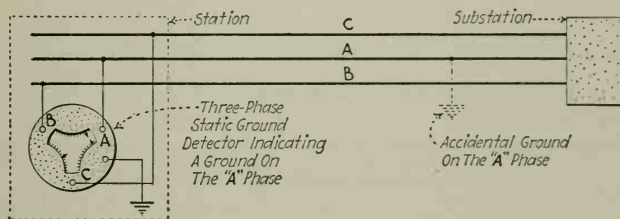


FIG. 79.—Accidental ground on a three-phase ungrounded system indicated by the ground detector.

80. When A Feeder Circuit-Breaker Opens it may be due to an instantaneous overload or surge, or it may be due to a fault which has occurred on the line. Therefore, when a feeder circuit-breaker opens, the operator closes it. If it opens again, he usually closes it the second time. If the breaker opens instantaneously three times in succession, it is usually due to a fault on the line. This fact is then reported by the operator to the proper person who begins the necessary steps for the location and removal of the fault as described in the following sections. If, however, upon the first or second time the breaker is closed it remains closed, the trouble was probably due to a sudden overload, or else there was a fault which burned itself clear. A ground or short-circuit which thus burns itself clear, usually does so by burning the conductor in two. This of course results in an open-circuit (Sec. 192).

81. A Fairly Accurate Open-Circuit Test Can Usually Be Made On Lines, Which Operate At 2,300 Volts Or Above, (Fig. 80) by the trouble man at the disconnect switch. This is done by touching the head of the switch-stick to the station-side terminal of the opened disconnect switch out on the line while the station circuit-breaker is closed. If the terminal which is touched is at a high potential, the static discharge will cause a visible spark to jump between the terminal and the

switch-stick head. This is ordinarily called *testing for static*. The desirability of making such a test will be made clear from the following: Assume that the circuit-breaker originally opened due to a ground in the underground line and that subse-

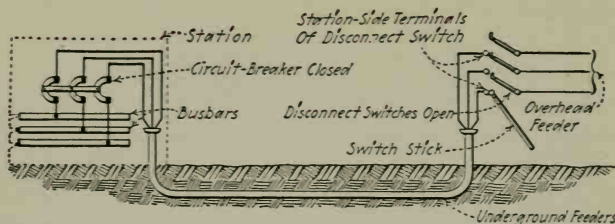


FIG. 80.—“Testing for static” with switch-stick to determine whether or not there is an open-circuit between the disconnect-switch and the station.

quent closures of the breaker has burned it into an open-circuit. Then when the trouble man opens the disconnect switch and the station operator closes the circuit-breaker it remains closed. Since it remains closed the conclusion might be that the fault is on the load side of the disconnect switch when in reality it is on the station side of the disconnect. However, if the static test does not give a spark when the circuit-breaker is closed, it is an indication that the conductor is open between the point at which the test is made and the station.

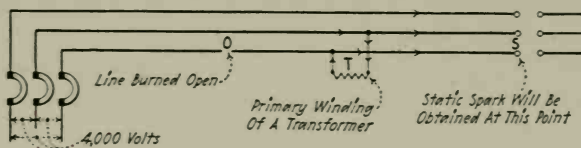


FIG. 81.—Showing how a transformer may cause the static test to test “closed” when it is actually open.

82. NOTE.—THE STATIC TEST MAY BE MISLEADING IF A TRANSFORMER IS CONNECTED TO THE LINE (Fig. 81) between an open and the point where the test is made. In Fig. 81 the conductor is open at *o*. The static test at *S* will give a spark because that point is charged through the winding of the transformer, *T*. However if the transformer is disconnected from the line, the static test will show an open.

83. The Method Of Procedure Which Is Followed In Locating A Fault On Underground Lines Differs Somewhat From That On Overhead Lines.—If the entire line is underground,

proceed as outlined in Secs. 84 to 183. If the fault is on an overhead pole line, see Secs. 184 to 187. If the line in which a fault develops is part underground and part overhead, first determine whether the fault is in the underground portion or in the overhead portion as explained in the following section. Then, after this has been determined, the fault is located according to the methods for that portion of the line in which it exists, as described in the above-mentioned sections.

84. When A Fault Opens The Circuit-Breaker Of A Permanently Grounded Line, A Part Of Which Is Overhead And Part Underground, the first thing that is ordinarily done is to open the disconnect switch (see following note) at the point (Fig. 80) where the construction changes from underground to overhead. After this is done, the station operator closes the circuit-breaker. If the breaker stays closed, the ground or short-circuit which originally caused it to open has either burned an open-circuit (Sec. 193) or the fault is in the overhead portion of the line. If the circuit-breaker again kicks out after the disconnect switch is opened, the fault still exists and is somewhere between the disconnect switch and the station; that is, it is in the underground cable. If there is more than one aerial line served by an underground line, then each aerial line in turn is disconnected until it is determined in which portion of the line the fault exists. Before attempting to make any of the tests, with instruments or test sets out on the line, which are hereinafter described, the tester should be certain that the circuit on which he is working is *open* at its supply end or ends and that it is not connected to any source of voltage that might damage his instruments or be dangerous to life.

85. NOTE.—THE DISCONNECT SWITCHES WHICH SHOULD BE OPENED are those which are in the same conductor as that which contains the circuit-breaker that has opened. Thus, three-phase, four-wire, permanently-grounded feeders are frequently protected by three single-pole circuit-breakers, one in each ungrounded conductor. Thus, an accidental ground on one of the ungrounded conductors will open only the circuit-breaker of the conductor in which the fault has developed. Consequently, when determining whether the fault is in the underground or aerial portion of the line as explained above, only the disconnect switch of the faulty conductor is opened. If a line is protected by a multi-pole circuit-breaker, then the disconnect switches in all of the conductors are opened.

86. The Nature Of The Fault In An Underground Cable Should Be Determined before any attempt is made to locate it. That is, tests should be made to ascertain whether the fault is a ground, a short-circuit, an open-circuit, or a combination of two or more of these, and which of the conductors contain faults. If the fault is a ground or a short-circuit, the approximate resistance of the fault should also be determined. How these facts may be ascertained by a test lamp at the station is explained in the following sections.

87. NOTE.—CONVENIENT APPARATUS TO USE IN TESTING TO DETERMINE THE NATURE OF THE FAULT (Figs. 82, 83 and 84) is a test lamp (Sec. 10) and the station-lighting circuit.

88. NOTE.—IN MAKING THE GROUND TEST ON A FEEDER (Fig. 82), one side of the test circuit should be grounded as at *G*. If the circuit

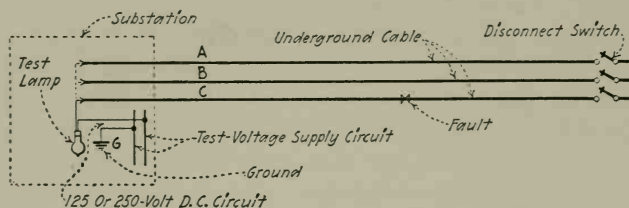


FIG. 82.—“Lamping out” to determine the approximate resistance of the ground and to determine which conductor or conductors are grounded.

from which the test lamp receives its supply has one side permanently grounded, this permanent ground may be utilized by connecting one terminal of the test lamp to the “hot” side of the test-lamp supply circuit. Otherwise, one side of the test-lamp circuit should be temporarily grounded to the metal sheath of the cable or to a water pipe. The test to determine if any conductors are grounded is made by successively touching one of the test-lamp terminals (Fig. 82) to each of the conductors of the line. When those conductors which have a low-resistance ground are touched, the lamp will light. If the lamp does not light when a conductor is touched, that conductor is not grounded at the test-circuit voltage (Sec. 87). After making the *ground test* as thus outlined, the conductor which is found to be grounded is the *faulty conductor* and the conductor which is found to be ungrounded is the *good conductor*.

89. NOTE.—IF NO GROUND IS SHOWN BY THE GROUND TEST (Sec. 93), the reason is that the fault is not a ground, or that the resistance of the ground is so high (Sec. 94) that the test voltage does not impel sufficient current through it to light the lamp. Therefore, if the ground test does not indicate that one of the conductors is grounded, the short-circuit

test (Sec. 90) and the open-circuit test (Sec. 91) should be made before an attempt is made to break down the fault (Sec. 92).

90. The Test For A Short-Circuit is made as indicated in Fig. 83. One of the test-lamp terminals is connected to one side of the station-lighting circuit. A wire (*W*, Fig. 83) is connected to the other side of the same circuit. The other

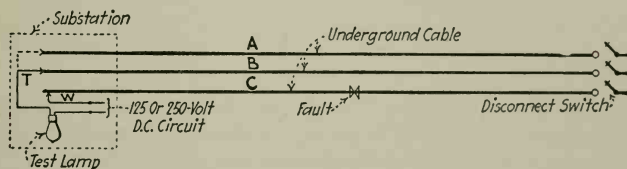


FIG. 83.—“Lamping out” for a short-circuit test at a sub-station.

test-lamp terminal, *T*, and the free end of the wire, *W*, form the testing terminals. These terminals, *T* and *W*, are touched to each possible combination of pairs of conductors in the faulty line. Thus, in the three-conductor line of Fig. 83, with *W* on *C* touch *T* to each *A* and *B*. Then, with *W* on *B*, touch *T* to *A*. If the lamp lights, the two conductors which are then being touched are the ones which are short-circuited.

91. The Test For Open-Circuits (Figs. 84) is made after both the ground test (Sec. 88) and short circuit test (Sec. 90) show that neither of these faults exist. Before making the test for an open-circuit, loop the line conductors together

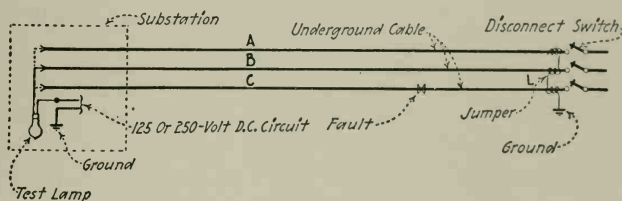


FIG. 84.—“Lamping out” for an open-circuit or continuity test.

(*L*, Fig. 84) with a jumper at the disconnect switch at the end of the cable and then ground them as indicated. The “looping together” can be done by clamps (Sec. 4), or by merely wrapping a piece of No. 8 or No. 10 copper wire tightly around the switch terminals. The ground can ordinarily be

made to a near-by water plug, or a driven pipe. After the ends of the conductors in the cable line are thus connected together and grounded, the test for an open-circuit is made by touching the conductors in the same manner as that described in Sec. 88 for grounds. If the lamp does not light when a conductor is touched, it indicates that that conductor has an open-circuit. If there are no short-circuits on the line (Sec. 90) and the lamp lights on all wires, it indicates that there are no open-circuits.

92. NOTE.—IF NONE OF THE TESTS ON A HIGH-VOLTAGE CABLE, AS OUTLINED IN THE ABOVE SECTIONS, SHOW A FAULT, it is probable that the trouble is a high-resistance ground. In this event an attempt to break down the fault should be made (Secs. 96 to 101).

93. NOTE.—THE ABOVE TESTS SHOULD PREFERABLY BE MADE WITH DIRECT-CURRENT.—If an alternating-current circuit is used as the test-lamp-supply circuit, the charging current may be sufficiently large to light the test lamp, thus leading to wrong conclusions concerning the condition of the cable.

94. The Resistance Of A Ground Or A Short-Circuit Which Is To Be Located In An Underground Cable, Must Not Be Excessive.—The maximum permissible value of the resistance of such faults, which will permit their location, cannot be definitely stated. This value will, when the resistance method (Sec. 103) of locating the fault is used, depend upon the sensitiveness of the galvanometer and upon the available test voltage. In any event, the resistance of the fault must be low as compared to the insulation resistance of the remainder of the cable and its connections. If the resistance of the fault is so high that an extremely large test voltage is required to obtain sufficient current for the test, the current leakage will introduce errors in the readings. With a fairly sensitive galvanometer and a test voltage of 220 volts, faults which have a resistance of 2,000 or 3,000 ohms can be accurately located by the loop method (Sec. 104).

95. NOTE.—CABLES WHICH OPERATE AT HIGH VOLTAGE WILL SOMETIMES SHOW A BAD GROUND AT THEIR OPERATING VOLTAGE, BUT AT THE TEST VOLTAGE, OF SAY 125 OR 250 VOLTS, WILL TEST CLEAR (Sec. 89); that is, at this lower voltage, the fault is not apparent. The reason for this is that in a high-tension-cable fault, there is ordinarily no metallic path between conductors, or between conductors and ground.

A thick wad of paper or other insulation ordinarily separates the conductors from one another and from ground. In order to test and locate the fault, a path of low resistance at the fault between conductors, or between a conductor and the sheath or ground, must be made. This is accomplished by the application of a voltage high enough to start a flow of current across the gap. The amount of current which is made to flow across the gap should be just enough to carbonize the insulation without destroying the insulating material by combustion. This is called "breaking down" a fault. How this can usually be done is explained in the following section.

96. The Two Methods Which Are Used In Breaking Down A High-Resistance Ground are, in the order of preference:

(1) *Mercury-arc rectifier which is supplied by a constant-current transformer, Sec. 97.* (2) *Alternating current from constant-potential transformer, or generator, Sec. 99.* Each of these methods are described in following sections.

97. In Breaking Down A Fault With A Mercury-Arc Rectifier Which Is Supplied By A Constant-Current Trans-

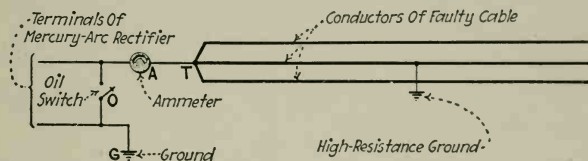


FIG. 85.—Breaking down a high-resistance fault with a high-voltage mercury-arc rectifier.

former (Fig. 85), the movable coil of the transformer is raised as far away from the stationary coil as is possible and fastened there. One terminal of the direct-current side is grounded, *G*, to the cable sheath, a water pipe, or other suitable ground. The other terminal, *T*, is connected to all of the conductors of the faulty cable. The two terminals of the rectifier are short-circuited through an oil switch, *O*, and the rectifier is started. Then, the oil switch, *O*, is opened, thus impressing the full rectifier voltage across the fault. The ammeter, *A*, will indicate the amount of current which is flowing through the fault. This current, say 6 or 7 amp., is permitted to flow through the fault for 5 or 10 min. to insure that it has been thoroughly carbonized.

98. NOTE.—THE MERCURY-ARC RECTIFIER WHICH IS GENERALLY USED BY MOST CENTRAL STATION COMPANIES is a spare from a series lighting circuit. The direct-current voltage may be anything from 2,500 to 8,000 volts. The separation between the coils of the constant-current transformer automatically limits the current to safe values. Where the faulty cable terminates at a station where there is located a spare mercury arc rectifier, this is probably the best means of breaking down a fault.

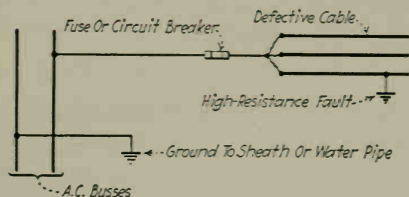


FIG. 86.—Breaking down a fault by connecting the defective cable directly to alternating-current busses which carry voltage at the normal operating voltage of the cable.

alternating-current generator (Fig. 86) should not be used unless a spare generator is available. In this case, the generator should be brought up to normal speed with its voltage reduced to its minimum by the generator-field rheostat. Then increase the voltage gradually until the fuse or circuit-breaker, *F*, opens. If the faulty conductor is connected to a generator which suddenly impresses the normal operating voltage of the cable on the fault, surges may occur and result in considerable damage to either the cable or the generator. If a spare high-voltage generator is not available, the energy required to break down the fault may be obtained from a low-voltage system by means of transformers as explained in the following section.

99. A High-Resistance Fault May Be Broken Down With Alternating Current (Figs. 86 and 87) by connecting the defective cable directly to an alternating-current generator, or to a bank of transformers. The direct connection to an

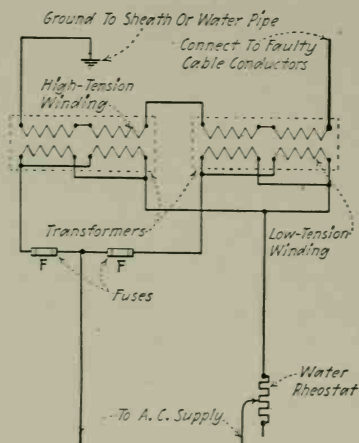


FIG. 87.—High-voltage from transformers for breaking down a fault in a cable.

100. In Breaking Down A Fault With A Transformer, the capacity of the transformer must be sufficient to carry the charging current of the line. This is the principal objection to the use of transformers, because for long high-voltage cables extremely large transformers may be required. However, where high-voltage direct-current is not available, the transformer method will serve. In most cases, where it is necessary to break down a fault preparatory to locating it, the voltage necessary to force sufficient current through it for carbonization will not exceed one-half or two-thirds that of the operating voltage. See the following note.

101. A METHOD OF BREAKING DOWN A FAULT WITH TRANSFORMERS is illustrated in Fig. 87. The connections indicated will impress upon the fault a voltage equal to twice that of the transformation ratio. The two transformers should preferably be of the same capacity and have the same ratio of transformation. Care must be taken that the high-tension windings of the two transformers are so connected that their voltages will not oppose each other. The current-carrying capacity of the fuses, *FF*, should be such that the transformer cannot be overloaded. When starting up, the water rheostat is arranged to have a high resistance. This resistance is slowly decreased until the fuses blow. It sometimes happens that the fault will arc over and cause the fuses to blow before the current through the fault has time to carbonize the insulation. In this case, another fuse should be put in and the process repeated, but the resistance should be cut out at a slower rate.

102. The Location Of Faults In Conductors By Electrical Measurements ordinarily comprises the measuring of resistance in locating short-circuits and grounds, and the measuring of capacity in locating open-circuits. The instrument which is ordinarily employed in making such measurements is some sort of modification of the Wheatstone bridge. Instruments of this type are described in Div. 1. Although the commercial Wheatstone bridge (Secs. 28 to 35) is not generally employed for such measurements in low-resistance conductors (Sec. 39), it is widely used for high-resistance conductors in telephone work. For these reasons a brief explanation of the methods of connection and computation, when such a device is used, will be included herein. The principles upon which are based the location of faults in transmission and distribution underground lines by measuring resistance and capacity, and the

practical methods for making such measurements, are described in following sections.

103. There Are Two General Methods Of Locating Faults By Resistance Measurements.—One of these methods is called the *Murray-loop* method (Sec. 104). The other is called the *Varley-loop* method. The *Murray-loop* or some modification of it is the one which is most frequently used. The *Varley loop* (Sec. 106) is better adapted to the measurements for locating faults in relatively high-resistance conductors than it is to those in low-resistance conductors.

104. The Diagrammatic Connections For The Murray-Loop Test are shown in Fig. 88. To make this test it is necessary to have available, in addition to the faulty conductor, a good conductor, *A* (Sec. 88) which extends from the location

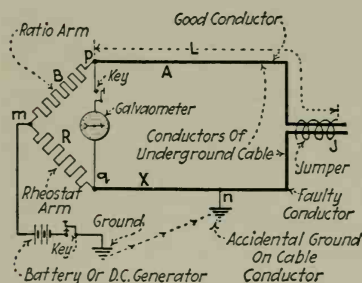


FIG. 88.—Diagram of connections for the Murray-loop test.

at which the test readings are to be made to some accessible point beyond the fault. Also, the length and size, or the resistance, of each of these conductors must be known. At one end of the line, the available good conductor is, with a jumper, *J*, connected to the faulty conductor, thus forming the loop. Two arms, *B* and *R*, of a Wheatstone

bridge are connected to the other ends of the same to conductors. The battery or direct-current generator and the galvanometer, with the necessary keys are connected as shown. The resistance of the rheostat arm, *R*, is adjusted so that the galvanometer is balanced. When this condition is obtained, the Wheatstone bridge formula (For. 1, Sec. 24) applies. Thus:

$$(1) \quad X = R \times \left(\frac{A}{B}\right),$$

wherein: *X* = the resistance, in ohms, of the conductor from the testing point to the fault (*q* to *n*). *A* = the resistance, in ohms, of the rest of the loop from the fault back to the testing point (*n* to *p*). *B* and *R* = the resistances, in ohms, in the respective bridge arms.

But as yet, the resistance of neither X nor A is known. However, the total resistance of the loop, $X + A$, is known from the conditions which are necessary for the test. Call this total resistance K . Then $X + A = K$, or transposing, $A = K - X$. Substituting this value in the Wheatstone bridge formula, there results:

$$(7) \quad X = R \frac{K - X}{B} \quad (\text{ohms})$$

Or by transposition,

$$(8) \quad X = \frac{RK}{B + R} \quad (\text{ohms})$$

Wherein: K = total resistance, in ohms, of the good and the faulty conductors which form the loop. B , R and X are as indicated above.

105. EXAMPLE.—A No. 00 copper conductor 12,000 ft. long has a ground somewhere in it. The good wire which is used for locating the fault is a No. 10 galvanized telephone wire which is 14,000 ft. long.

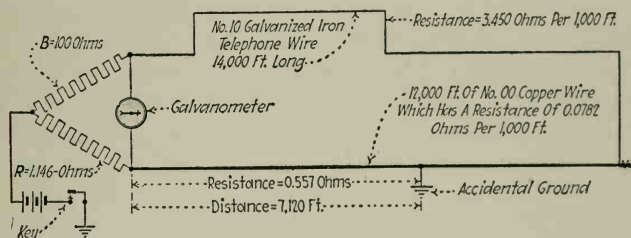


FIG. 89.—Illustrating example of locating a ground in a copper conductor by using a telephone wire as one conductor.

At the existing temperature the resistance of the copper conductor is 0.0782 ohms per 1,000 ft. and the resistance of the telephone wire is 3.450 ohm per 1,000 ft. In applying the Murray-loop test to locate the fault in the copper conductor, the galvanometer balances with the arm B (Fig. 89) at 100 ohms and the rheostat arm R at 1.146 ohms. How far is the fault from the point where the test is made? **SOLUTION.**—The total resistance of the copper cable = $(0.0782 \times 12,000) \div 1,000 = 0.9384$ ohm. The total resistance of the telephone wire = $(3.450 \times 14,000) \div 1,000 = 48.30$ ohms. Therefore, the total resistance, K , of the loop = $48.30 + 0.9384 = 49.2384$ ohms. By For. (8), the resistance of the conductor from the testing point to the fault, $X = RK \div (B + R) = (1.146 \times 49.2384) \div (100 + 1.146) = 56.427 \div 101.146 = 0.557$ ohm. Since the copper has a resistance of 0.0782 ohm per 1,000 ft., the distance

from the testing point to the fault = $(0.557 \div 0.0782) \times 1,000 = 7.24 \times 1,000 = 7,120$ ft. This example is given merely to illustrate the principle. Accurate results cannot ordinarily be obtained if the two conductors—the good one and the faulty one—have such a great difference in resistance as that indicated above.

106. The Diagrammatical Connections For The Varley-Loop Test are shown in Fig. 90. As in the Murray-loop test, one good conductor, which runs from one end of the faulty

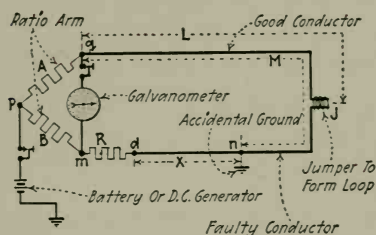


FIG. 90.—Diagram of connections for the Varley-loop test.

conductor to the other end, is required. It is also required that the resistance of these two conductors be known. The good conductor and the faulty conductor are looped together, *J*, at the far end of the line. It will be noted (Fig. 90) that in this test, three arms of a Wheatstone bridge

are employed. These arms are (Sec. 24) the two ratio arms *A* and *B* and the rheostat arm *R*. The galvanometer is balanced by choosing the proper ratios *A* and *B* and then adjusting the value of *R*. When this is done, the resistance of the faulty conductor from the point of test to the fault may be computed by the following formula:

$$(9) \quad X = \frac{BK - AR}{A + B} \quad (\text{ohms})$$

Wherein: *X* = resistance, in ohms, of the faulty conductor from the point of the test to the fault. *K* = the total resistance, in ohms, of the good conductor and the faulty conductor. *A*, *B* and *R* = respectively, the resistance in ohms, of the ratio arms *A* and *B* and of the rheostat arm *R*, of the bridge when the galvanometer is balanced. The derivation of this formula is presented below.

107. DERIVATION.—The equation which results from applying the Wheatstone bridge formula (For. 1, Sec. 24) to the connections of Fig. 90 is:

$$(10) \quad \frac{A}{B} = \frac{M}{R + X}$$

Wherein: A , B and R = respectively, the resistance, in ohms of the bridge arms, A , B , and R . X = the resistance of the faulty conductor (d to n) from the point of test to the fault. M = the resistance, in ohms, of the faulty conductor from the fault to the loop plus the resistance in ohms of the good conductor. In this equation there are two unknown values, M and X . However, the total resistance, in ohms, of the good and the faulty conductor is known. Call this resistance K . Then, $K = M + X$. Or transposing, $M = K - X$. Since $M = K - X$, the quantity $K - X$ can be substituted for M in For. (10). Hence,

$$(11) \quad \frac{A}{B} = \frac{K - X}{R + X}$$

By multiplying For. (11) by $B(R + X)$, there results:

$$(12) \quad AR + AX = BK - BX$$

By transposing For. (12):

$$(13) \quad AX + BX = BK - AR$$

Dividing For. (13) by $(A + B)$:

$$(14) \quad X = \frac{BK - AR}{A + B} \quad (\text{ohms})$$

Which is the same as For. (9).

108. EXAMPLE.—A three-wire cable of No. 0000 conductors is 11,380 ft. long. One of the conductors is grounded. When the connections are

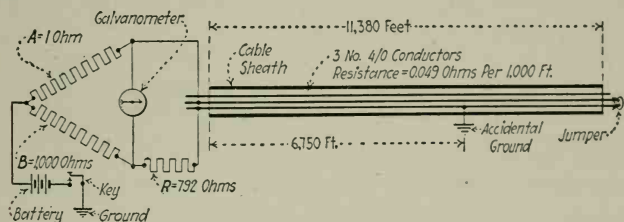


FIG. 91.—Illustrating an example of locating a fault by the Varley-loop test.

made to one good conductor and the faulty conductor as shown in Fig. 91 the bridge is balanced with the following readings: $A = 1$, $B = 1,000$ and $R = 792$. How far is the ground from the point of the test? **SOLUTION.**—The temperature of the conductor is 68°F . At this temperature, the No. 0000 stranded conductor has a resistance of 0.049 ohm per 1,000 ft. Therefore, the total resistance of the good conductor and the faulty conductor = $0.049 \times (11,380 + 11,380) \div 1,000 = 1.115$ ohms. Therefore by For. (9), the resistance of the faulty conductor from the point of test to the fault, $X = (BK - AR) \div 1,001 = 323 \div 1,001 = 0.322$ ohms. Since, the resistance of the conductor is 0.049 ohm per 1,000 ft., the distance to the fault from the point of the test = $(0.322 \div 0.049) \times 1,000 = 6.57 \times 1,000 = 6,570$ ft.

109. In Locating A Fault By Determining The Resistance, in ohms, of the faulty conductor from the point at which the

test is made to the fault (Secs. 105 and 108), the temperature of the conductor must be considered. The reason for this is that the resistance of a copper conductor varies about 0.2 per cent per degree Fahrenheit change in temperature. Thus, if the resistance is computed at a temperature which is say 10° F. above or below the actual temperature, the result will be in error by 2 per cent, or about 400 ft. on a fault 20,000 ft. away. Furthermore, a table of resistances must be available and the computation is somewhat long. Since the length of a cable, which is of uniform cross-sectional area, is directly proportional to the resistance, the total length of the loop (Sec. 104) may be used in the formula instead of the total resistance of the loop. When this is done, the temperature of the cable can be neglected provided the temperature is the same throughout the entire length during the time at which the test is made. Where the two conductors are in the same underground-cable sheath, the temperature will usually, but not always, be the same throughout the entire length. How the total length is used in For. (8) is explained below.

110. NOTE.—WHEN THE CABLES OF THE TEST LOOP HAVE THE SAME CROSS-SECTIONAL AREA, that is, when both cables of the loop are of the same gage number, and when they are in the same sheath, their resistances will, for all practical purposes, be equal. Call L the distance, in feet (Figs. 88 and 90) from the point of the test to the point where the loop is made. Then the total length of the loop will be $2L$. Since the total resistance (K) of the legs is proportional to the total length ($2L$) of the loop, K is proportional to $2L$. Therefore, in the Murray-loop method (Sec. 104) by substituting $2L$ in For. (8) there results:

$$(15) \quad X = \frac{2RL}{B + R} \quad (\text{feet})$$

Wherein: X = the distance, in feet, measured along the cable from the point of the test to the fault. R and B = the resistance, in ohms, of the bridge arms of Fig. 88. L = the total length, in feet, of the cable. See the example of Sec. 112. This simple substitution is not applicable to the Varley-loop method. Therefore, with the Varley-loop method, the resistance in ohms of the conductor to the fault must be determined. Then this value is converted into feet. This is one reason why the Varley-loop method is not as readily applicable to locating faults on low-resistance transmission lines as is the Murray-loop method.

111. NOTE.—WHEN THE LOOP CONSISTS OF CONDUCTORS OF DIFFERENT RESISTANCES PER UNIT LENGTH, the various resistances must be

reduced to equivalent lengths of one of the conductors of the loop. The largest conductor is ordinarily selected, and the resistances of the others reduced to its equivalent length. To do this, *divide the total resistance of the smaller conductor by the resistance per foot of the larger conductor.* The result will be the length in feet of a conductor of the larger size which would be required for its resistance to be equal to that of the smaller conductor. Thus, in Sec. 105, the total resistance of the telephone wire is 48.30 ohms. The resistance per foot, of the No. 00 copper conductor is $0.078,2 \div 1,000 = 0.000,078,2$ ohm. Therefore, $48.30 \div 0.000,078,2 = 617,647$ which means that 617,647 ft. of No. 00 copper conductor would be required to have a resistance equal to that of a No. 10 telephone wire 14,000 ft. long.

112. EXAMPLE.—Solve the example of Sec. 105 by using the lengths of the conductors instead of the resistances. **SOLUTION.**—The total length of the loop formed in Sec. 105 by the 14,000 ft. of No. 10 telephone wire and the 12,000 ft. of No. 00 copper conductor would be equivalent (Sec. 111) to: $617,647 + 12,000 = 629,647$ ft. of No. 00 copper conductor. For. (8) then becomes: $X = (629,647 \times R) \div (B + R) = (629,647 \times 1.146) \div (100 + 1.146) = 721,580 \div 101.146 = 7,130$ ft. which is the distance along the cable from the point of test to the fault. The difference of 10 ft. between this result and that of Sec. 105 is due to the difference in decimal places which were dropped.

113. The Necessity For Connecting The Ends Of The Conductors Together To Locate A Fault will be apparent from a consideration of Figs. 88 and 90 and Sec. 24. The resistance of X (Figs. 88 and 90) could be measured directly with a Wheatstone bridge by connecting X_1 and X_2 of the bridge directly to the faulty conductor and to ground (Fig. 92) provided the resistance of the fault, F , and that of the ground, G , were zero. But since the resistance of these grounds is never zero, their resistance will enter into the result obtained. Consequently the result will be in error by

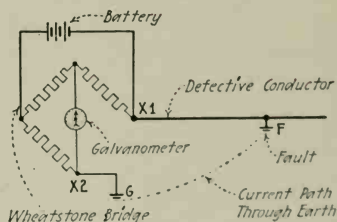


FIG. 92.—A fault cannot be located by measuring directly the resistance of the faulty conductor, because of the resistance of the two grounds G and F .

an amount which is equal to the sum of the resistances of F and G . However, by the loop methods (Secs. 104 and 106), these two grounds are placed in the battery circuit. When so placed in the battery circuit, their resistances may be

anything in reason and they will not affect the accuracy of the measurements, so long as they are sufficiently low to permit enough current to flow to actuate the galvanometer.

114. The Most Practicable Method Of Locating Accidental Grounds By Resistance Measurements is by adapting the principle of the Wheatstone bridge to some apparatus which gives the distance, from the point of the test to the fault, directly as a percentage of the total length of the line. When such methods are employed a chart or map should be provided which shows the location and length of the lines and the distance of each manhole from the station. Then when the fault-locating bridge is balanced, the percentage which is read from it is multiplied by the total length of the line. This result gives the distance to the fault. Then by scaling or reading this distance from the map or chart, the two poles or manholes between which the fault is located can be determined. Various instruments of this type are described in following sections.

115. To Locate A Fault With The Home-Made Fault Locator, described in Sec. 44, the connections are made as

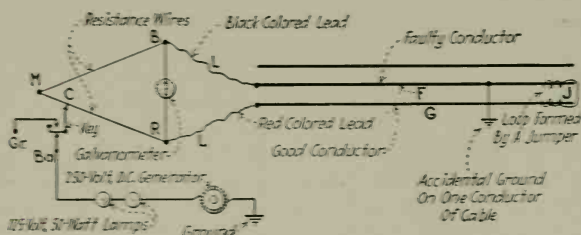


FIG. 93.—Diagram of connections for locating a fault with the home-made fault localizer.

indicated in Fig. 93. The faulty conductor, *F* is looped (as at *J*) to a good conductor, *G*, which is of the same gage and length as *F*. The red-colored lead is connected to the good conductor. The black-colored lead is connected to the faulty conductor. The galvanometer leads. The "hot" side of a 250-volt direct-current circuit is connected through two 125-volt, 50-watt lamps in series, to the terminal *Ba*. The other side of the 250-volt circuit must be grounded. If a 125-volt circuit is used, omit

one of the lamps. Then, when the key is closed, a current of not over 0.5 amp. will flow through the fault. Adjust the sliding contact, *C*, until the galvanometer is balanced. Then multiply the percentage as read from the scale under the pointer by the total length of the line. The result is the distance to the fault. If the slider must be moved to the 100 per cent graduation without obtaining a balance, it indicates that the fault is in what was assumed to be the good conductor. In this case, the black and red leads must be interchanged on the line conductors.

116. EXAMPLE.—After having “lamped out” the line (Sec. 88 of a three-wire underground cable line which is 22,380 ft. long, it is found that one of the conductors is grounded and that the other two are good.

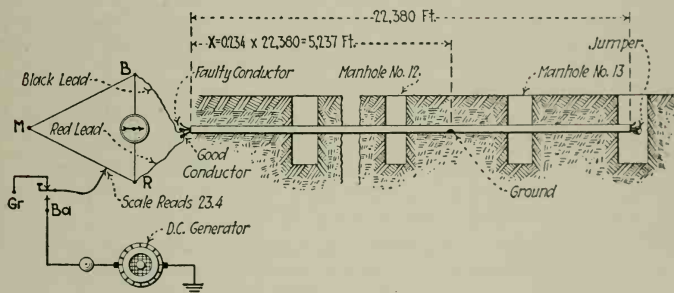


FIG. 94.—Illustrating an example of locating a ground with the home-made fault-finder.

The faulty conductor is looped to one of the good conductors at the far end of the line, and the connections made as shown in Fig. 94. The galvanometer shows no deflection when the pointer of the slider indicates 23.4 per cent. Where is the fault? **SOLUTION.**—The reading indicates that the distance of the fault from the station is 23.4 per cent of the length of the line. Hence, the distance to the fault = $22,380 \times 0.234 = 5,237$ ft. Reference to a map of the system shows that manhole No. 12 is 4,980 ft. from the station and manhole No. 13 is 5,310 ft. from the station. Therefore the ground is somewhere between manholes No. 12 and 13.

117. NOTE.—THE ACCURACY OF FAULT LOCATION IN AN UNDERGROUND-CABLE SYSTEM WHICH IS INSTALLED IN CONDUIT does not need to be any closer than the distance between manholes. This is because if the fault is in the section between two manholes, the entire section must be pulled out in any event. However, when a fault occurs and it appears to be located between two manholes, the condition of the joint

at the two adjacent manholes should be thoroughly examined before the cable is cut. If the rupture occurred in the joint, as is frequently the case on high-voltage cables, it can sometimes be accurately located by inspection and repaired without cutting and pulling out the cable.

118. NOTE.—HOW THE HOME-MADE FAULT LOCATOR OPERATES IN ACCORDANCE WITH THE PRINCIPLE OF THE WHEATSTONE BRIDGE may be understood from the following: Consider Fig. 95. The resistance wire

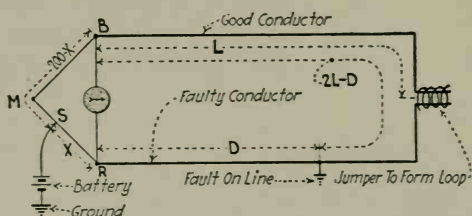


FIG. 95.—Illustrating why the scale reading, as read from the home-made fault-finder, multiplied by the length of the line gives the distance to the fault.

MB has the same resistance as *MR*. The slider, *S*, can only contact with the wire *MR*. The wire *MR* is, by the scale, marked off into 100 equal parts. Call each part a "unit of resistance." Then, there are 100 "units of resistance" in each wire. Call *D* the distance to the fault, and *L* the length of the line. Since the good and bad conductor are of the same size and material, the total resistance of the loop is proportional to its length. When the bridge is balanced, call the scale reading *X*. Then *X* = the number of "units of resistance" between *R* and *S* as shown in Fig. 95; also $200 - X$ = resistance between *S* and *B*. Applying the Wheatstone bridge formula (For. 1, Sec. 24), there results:

$$(16) \quad \frac{200 - X}{X} = \frac{2L - D}{D}$$

Transposing and combining:

$$(17) \quad D = \frac{X}{100} L$$

And since $\frac{X}{100}$ is the percentage reading of the scale, the distance, *D*, to the fault = the length, *L*, of the line multiplied by the reading of the scale in per cent.

119. In Locating A Fault With The L. & N. Power Bridge (Figs. 44 and 45), the connections are made to the faulty conductor and a similar good conductor as shown in Fig. 96. The bridge is balanced and the reading taken from the scale (Fig. 44). This reading multiplied by the total length of the

loop (twice the length of the line) and divided by 1,000 gives the distance from the bridge to the fault. This bridge employs the Murray-loop principle (Sec. 104). See the following example.

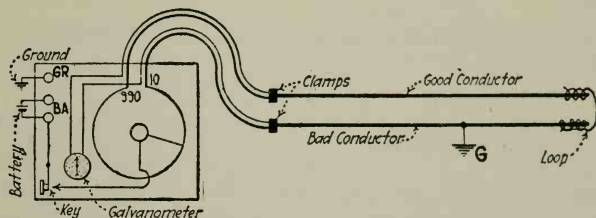


FIG. 96.—Diagram of connections for locating an accidental ground in a conductor with the L. & N. Power Bridge. (The Leeds & Northrup Co., Philadelphia, Pa.)

120. EXAMPLE.—One conductor of a cable which is 16,780 ft. long is grounded. An L. & N. Power Bridge, when connected as shown in Fig. 97, balances with a reading of 346. How far is the fault from the bridge. **SOLUTION.**—The total length of the loop = $2 \times 16,780 = 33,560$ ft. By the above rule, the distance from the bridge to the fault = $(346 \times 33,560) \div 1,000 = 11,610$ ft.

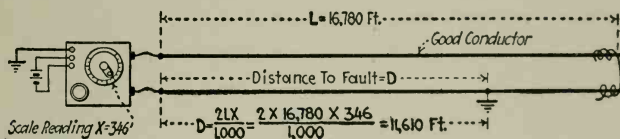


FIG. 97.—Example of locating a ground with the L. & N. Power Bridge.

121. A Diagram Of Connections Of The Westinghouse Portable Fault Localizer is shown in Fig. 98. The faulty conductor and its good mate are connected, one to the black binding-post and one to the red binding-post. The knob is adjusted until the galvanometer deflection is zero. The reading of the scale in per cent multiplied by the total length of the line is the distance of the fault from the tester. If the scale is in black figures the ground is in the conductor which is connected to the black binding-post. If the scale shows red figures, the ground is in the conductor which is connected to the red binding-post.

122. NOTE.—THE WESTINGHOUSE FAULT LOCALIZER OPERATES ON THE PRINCIPLE OF THE WHEATSTONE BRIDGE.—As shown in the connection diagram of Fig. 99, there is a heavy shunt, *S*, which carries the main current. This permits a relatively small slide wire. The slide

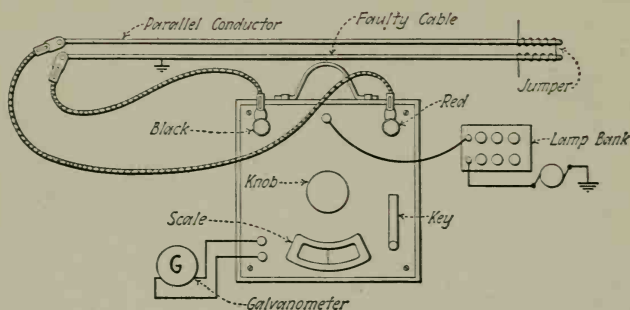


FIG. 98.—Diagram of connections for locating a ground with a Westinghouse portable fault localizer. (The Westinghouse Electric & Mfg. Co.)

wire, *W*, is wound on a circular spool in two sections, and on each section is a movable contact. The center point of the shunt is connected to the center point of the slide wire. Hence, the current between the center post and the fault divides through the two parts of the shunt in inverse

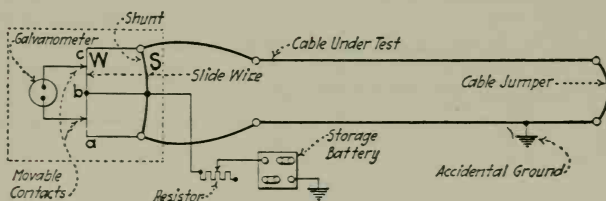


FIG. 99.—Circuit diagram of the fault localizer shown in Fig. 46 (D1).

proportion to the resistance of the two legs of the loop from the instrument to the fault. The currents in the two parts of the slide wire are directly proportional to the currents in the shunt. Hence, by moving the contacts so that they span more of one part, *ab*, of the slide wire than of the other part, *bc*, a point will be reached where balance obtains. This point, as indicated on the movable scale, gives the location of the fault in percentage of the length of the line.

123. The Approximate Location Of A Ground In A Feeder May Be Determined By The Two-Ammeter Method as indicated in Fig. 100. This is done by connecting one 5- or 10-amp. direct-current ammeter to the grounded cable and

another similar ammeter to its good mate. The other two leads of the ammeters are connected to a direct-current generator through some sort of a variable resistance such as a water rheostat or lamp bank. The grounded cable is looped to its good mate at the other end of the line as indicated. The current is adjusted to a value which will not be dangerous to either ammeter.

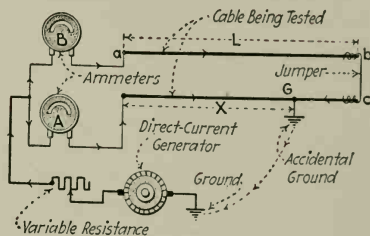


FIG. 100.—Localizing a fault by means of two ammeters.

Then the distance from the point of test to the fault may be computed by the following formula:

$$(18) \quad D = L \left(\frac{2B}{A + B} \right) \quad (\text{feet})$$

Wherein: D = distance, in feet, from the point of test to the fault. L = length, in feet, of the feeder under test; that is, it is the distance measured along the cable from the point of test to the loop. B = the reading, in amperes, of the ammeter which is connected to the good cable. A = the reading, in amperes, of the ammeter which is connected to the faulty cable. See the following example and derivation.

124. EXAMPLE.—One conductor of a two-wire cable which is 12,000 ft. long is grounded. To locate the ground, two ammeters are connected to the faulty cable and its good mate and to a direct-current generator, as shown in Fig. 100. The ammeter which is connected to the good cable reads 2.5 amp. The one which is connected to the faulty cable reads 3.5 amp. How far is the ground from the station where the ammeters are connected? **SOLUTION.**—The good cable reading, B , = 2.5 amp. The faulty cable reading, A , = 3.5 amp. By For. (18), the distance from the station where the test is made to the fault, $D = L \times \frac{2B}{(A + B)} = 12,000 \times (2 \times 2.5) \div (3.5 + 2.5) = 12,000 \times 5 \div 6 = 10,000$ ft.

125. DERIVATION.—IN THE TWO-AMMETER METHOD OF LOCATING A GROUND (Fig. 100), the circuit through the cable is divided into two parts. One part, X , comprises the faulty cable from the point of test to the ground. The other part, $abcg$, consists of the entire length of the good cable and that portion of the faulty cable from the loop back to the ground. The currents through the two parts of the circuit are inversely proportional to their resistances. And the resistances of the two parts

of the circuit are directly proportional to the length of the cable in each part. If the distance to the fault = X , and the total length of the feeder = L , the length of cable which the current through ammeter B traverses = $2L - X$. Therefore,

$$(19) \quad \frac{B}{A} = \frac{X}{2L - X}$$

Or,

$$(20) \quad 2LB - BX = AX$$

Whence,

$$(21) \quad X = L \frac{(2B)}{(A + B)}$$

Which is the same as For. (18). This method will ordinarily not be very accurate because of the unavoidable error in reading the ammeters. Furthermore, the resistance of the leads and the ammeters (Sec. 123) will, if not considered, cause an additional error.

126. Short-Circuit Faults In A Three-Or-More-Wire Line May Be Located By Resistance Measurement in essentially

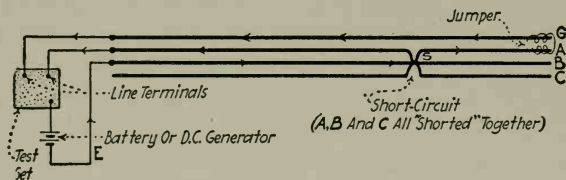


FIG. 101.—Diagram of connections for locating a short-circuit, when one good conductor is available, by the resistance method.

the same manner as grounds (Sec. 104 to 125), provided there is at least one conductor of the line that contains no fault. In locating a short-circuit by the method (Fig. 101), loop the good conductor to *one* of the faulty conductors at the far end of the line. Then at the point where the test is to be made, connect one of the line terminals, of whatever kind of test set is used, to the good conductor. Connect the other line terminal of the test set to the same conductor which is looped to the good conductor at the far end of the line. Then, connect the other side (E , Fig. 101) of the source of current supply to one of the conductors which is short-circuited. The bridge is balanced and the computations are made in exactly the same manner as that outlined in Secs. 104 to 125 for locating a ground.

127. NOTE.—IN LOCATING A SHORT-CIRCUIT BY THE RESISTANCE-MEASUREMENT METHOD as outlined in Sec. 126, it is essential that the connections be made as directed therein. That is, in Fig. 101, conductors *A*, *B* and *C* are short-circuited at *S*, and *G* is free from faults. If, in preparing for the test, *G* is looped to *A*, then the line terminals of the test set must be connected to *G* and *A*. The terminal, *L*, from the source of current may be connected to either one, *B* or *C*, or to all of the other faulty conductors. By so doing, the contact resistance of the short-circuit is put in the battery or generator circuit and is there by eliminated from the computations. With the test set connected as shown, if *G* and *B* were looped together, the contact resistance of the short-circuit would thereby be interposed in the bridge arm and the result would be in error. The amount of the error would depend upon the resistance between the conductors and the fault.

128. If All Conductors Of A Line Are Grounded Or Short-Circuited, it is practically impossible to locate the fault by the resistance-measurement method. Such faults must usually be located by some sort of tone-test method (Sec. 159).

129. The Two Principal Sources Of Error In Locating Faults By Resistance Measurements are in the leads and at the jumper. The effect of the resistance of the instruments leads between the line and the testing bridge may be eliminated, by properly calibrating the scale, as explained in Sec. 46. Unless some such method is employed which will compensate for the resistance of instrument leads, their equivalent length in terms of the line being tested must be computed and this length added to the length of the line. How this may be done is explained below. Another source of error which cannot be wholly eliminated, but which with proper care can be minimized, is the contact resistance between the instrument leads and the conductors being tested and also the contact resistance between the jumper and the conductors at the far end of the line at the location where the loop is completed. Every possible precaution should be taken to render the resistance of these joints as small as possible. The example given in Sec. 130 below will illustrate the importance of this feature.

130. The Method Of Compensating For The Resistance Of The Instrument Leads is explained by the following: A test is being made with the home-made fault locator (Fig. 102) on a No. 0000 underground cable line, which is 12,000 ft. long. Each of the two instruments leads (*L*, Fig. 93) consists of 6

ft. of No. 14 stranded copper wire. The resistance of No. 0000 copper cable is 0.000,049 ohm per ft., and the resistance of No. 14 stranded wire is 0.002,52 ohm per ft. By Sec. 111, 6 ft. of No. 14 copper wire has the same resistance as: $(0.002,52 \div 0.000,049) \times 6 = 310$ ft. of No. 0000 cable. Therefore, instead of considering the cable to be 12,000 ft.

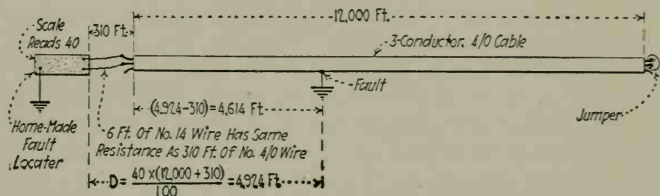


FIG. 102.—Illustrating method of compensating for the resistance of the instrument leads in locating a fault.

long it must be treated as though it were: $12,000 + 310 = 12,310$ ft. long. Consequently if the bridge balances at 40, the equivalent distance from the instrument to the fault is: $12,310 \times 0.40 = 4,924$ ft. But 310 ft. of this distance is contained in the 6 ft. of leads between the instrument and the fault. Therefore, the distance from the end of the cable where the leads are connected to the fault = $4,924 - 310 = 4,614$ ft. which is the distance to be measured, in feet along the line in localizing the fault. If the resistance of the lead wires had not thus been considered, the location of the fault would have been measured as: $12,000 \times 0.40 = 4,800$ ft. Hence, by neglecting the effect of the 6-ft. leads which were used in connecting the instrument, the error would have been: $4,800 - 4,614 = 186$ ft. Sometimes, such an error will not make any difference, but this error plus that due to the unavoidable contact resistance of the jumper and of the leads will very frequently throw the results out sufficiently to cause a "false cut."

131. NOTE.—A CONTACT RESISTANCE BETWEEN THE CABLE AND THE JUMPER WIRE (*J*, Fig. 93), by which the loop is formed, will also result in an error in the location of the fault. Thus, if there is a contact resistance of 0.01 ohm between each end of the jumper and the No. 0000 cable, the equivalent length of the line will be approximately 200 ft. longer than its actual length. Therefore, since there is no practical method of compensating for this contact resistance, it should be made as

small as is possible. That portion of the cable around which the jumper is served, and also the jumper wire, should be scraped bright to insure a contact of minimum resistance. The jumper wire should not be smaller than No. 8 or No. 10 gage and should be wrapped tightly around the cable or disconnect-switch terminals.

132. An Open-Circuit is said to exist when the continuity of an electric circuit is broken so that an appreciable current will not flow under the normal operating voltage of that circuit. If a wire of a circuit is broken and the two ends at the break are separated from each other, thus introducing a high resistance in the circuit, an *open-circuit* results.

133. NOTE.—THE TERM “OPEN-CIRCUIT” IS A RELATIVE ONE.—The two ends of a broken wire of a circuit may be separated by a small air gap, say $\frac{1}{16}$ in. long. If this condition existed in a 110-volt circuit it would usually constitute an open-circuit. However, if this condition existed in a 13,000-volt circuit, an arc would be established and a considerable current might continue to flow until the action of the arc burned a larger separation between the wires. For these reasons, the term open-circuit is a relative one.

134. An Open-Circuit On A Transmission Line usually manifests itself either by the opening of a circuit-breaker at the station or by a telephoned complaint of “no service” by one or more customers, or in both ways. If a circuit-breaker opens, the operator ordinarily closes it at least twice (Sec. 80) before he reports trouble. The reason for this is that some unusual surge or overload may have caused the breaker to open. Furthermore, a short-circuit or a ground may cause the breaker to open. Then when it is closed once or twice, the ground or short-circuit may burn clear, and finally result in a pure open-circuit. In this event, the breaker will remain closed. Then, the only indication which the operator can have that there is an open-circuit, is a large decrease in the ammeter reading. But if the open occurs at a great distance from the station, on a line which serves a large number of customers, the decrease in load may not be apparent from the ammeter reading.

135. The Method Which Is Ordinarily Employed In Locating An Open-Circuit In An Underground Cable Transmission Line utilizes the principle of the Wheatstone bridge in measuring

or comparing electrostatic capacities. In the following section the theoretical method of determining the capacity of a condenser by comparing it with a condenser of known capacity in the Wheatstone-bridge circuit (Sec. 24) is explained. Then, in Secs. 140 to 158, the practical applications of this principle in locating open-circuits is treated.

136. The Wheatstone-Bridge Circuit Diagram For Determining The Electrostatic Capacity Of A Condenser

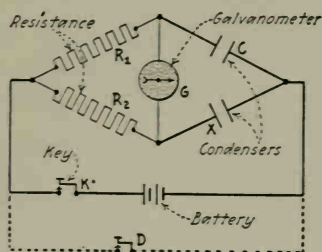


FIG. 103.—Wheatstone-bridge circuit diagram for determining the electrostatic capacity of a condenser.

The condenser X is the one whose capacity is to be determined. The resistances R_1 and R_2 are so adjusted that when the key, K , is closed the galvanometer G shows no deflection. The capacity of X is then computed by the following formula:

$$(22) \quad X = C \frac{R_1}{R_2} \quad (\text{microfarads})$$

Wherein: X = the electrostatic capacity, in microfarads, of condenser X (Fig. 103). R_1 and R_2 = respectively, the resistance, in ohms, of resistances R_1 and R_2 (Fig. 103). The truth of this formula will be evident from the following derivation.

137. DERIVATION.—When the resistances R_1 and R_2 (Fig. 103) are so adjusted that the galvanometer gives no “kick” when the key K is closed, then, at this instant, the following conditions exist: (1) *The value of the current, I_1 , which flows through R_1 is equal to that which is flowing through C ,* (2) *The value of the current (I_2) which is flowing through R_2 is equal to that which is flowing through X .* (3) *The voltage drop across R_1 ($I_1 R_1$) is the same as that across R_2 ($I_2 R_2$).* (4) *The voltage drop across C ($\frac{I_1}{C}$) is the same as that across X ($\frac{I_2}{X}$).* Therefore,

From (3) above,

$$(23) \quad I_1 R_1 = I_2 R_2$$

And from (4) above,

$$(24) \quad \frac{I_1}{C} = \frac{I_2}{X}$$

Dividing For. (23) by For. (24), there results

$$(25) \quad R_1 C = R_2 X$$

Or,

$$(26) \quad X = C \frac{R_1}{R_2}$$

Which is the same as For. (22).

138. EXAMPLE.—In measuring the capacity of a condenser (X , Fig. 104) a standard condenser is used at C which has a capacity of 0.02 microfarads. The galvanometer G balances when R_2 is set at 1,000 ohms and R_1 at 1,136 ohms. What is the capacity of X ? **SOLUTION.**—By For. (22), the capacity of the unknown condenser, $X = C \left(\frac{R_1}{R_2} \right) = 0.02 (1,136 \div 1,000) = 0.022,72$ microfarads.

139. In Measuring The Capacity Of A Condenser By The Above Method (Sec. 136), it is necessary that the condensers be discharged after each closure of the key K . If this is not done, the next time K is closed, there will be little or no deflection of G , regardless of whether the bridge is or is not balanced.

The condensers, C and X , may be discharged by closing an auxiliary key, D , (Fig. 103) which should be connected as indicated by the dotted lines. Then after each closing of K and adjusting of R_1 and R_2 , hold key D closed for an instant before K is closed for another reading. In determining the capacity of a condenser by this method, C should be so chosen that its capacity is as nearly equal to that of X as is possible. Then the bridge will balance with R_1 nearly equal to R_2 .

140. There Are Three Principal Methods Of Locating An Open-Circuit In A Multi-Conductor Underground Cable, each of which requires that there be one or more good conductors in the same sheath. These methods are: (1) *One good conductor without loop* (Sec. 142). (2) *One good conductor looped to the faulty conductor at the far end of the line* (Sec. 145). (3) *Two good conductors looped to the faulty conductor at both ends of the line* (Sec. 148). The use of each of these methods with different instruments is described hereinafter. If other instruments are used the same principles will apply. The

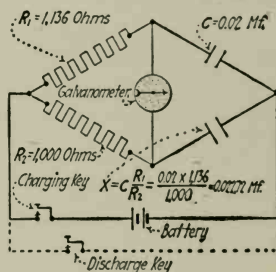


FIG. 104.—Illustrating an example of determining the capacity of a condenser.

similarity of each method to that of the Wheatstone-bridge circuit (Fig. 103) will be apparent by considering one conductor and the ground as the two plates of one condenser (C, Fig. 103) and the other conductor and ground as the two plates of the other condenser (X, Fig. 103).

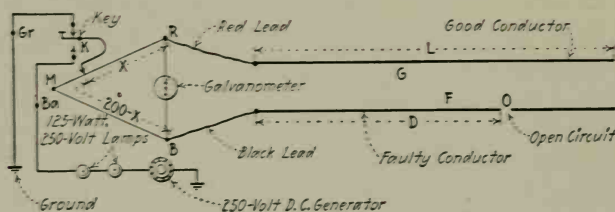


FIG. 105.—Locating an open circuit in a multi-conductor underground cable with one good conductor. The good and faulty conductors are not looped together.

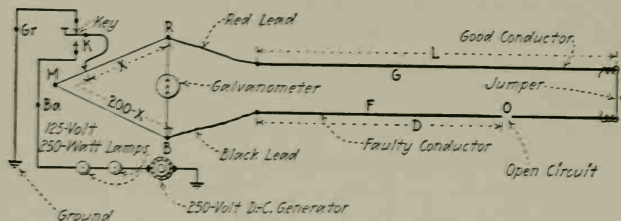


FIG. 106.—Locating an open circuit in an underground cable with one good conductor looped to the faulty conductor.

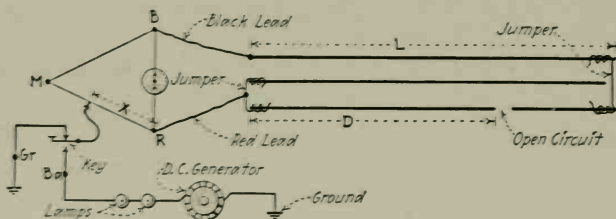


FIG. 107.—Diagram of connections for locating an open-circuit in a three-conductor cable, by means of the home-made fault locator, when the distance to the fault is greater than one-half the length of the line, with the faulty conductors looped to a good conductor at both ends of the line.

141. To Locate An Open-Circuit With The Home-Made Fault Locator (Sec. 44), the connections are made as indicated in Figs. 105, 106 and 107. Note that in locating an open-circuit with this device as shown in Figs. 105 and 106, the red-colored lead is connected to the good conductor and the black-

colored lead is connected to the faulty conductor. If the leads are reversed a balance cannot be obtained. If the galvanometer is sufficiently sensitive, a battery may be used instead of the generator and lamps. The double-contact key, K , will, if released after each observation of the galvanometer and adjustment of the slider, discharge the cable (139). This is the reason for the use of the double-contact key. The effect of the leads can ordinarily be neglected without appreciably affecting the results. Also, if one of the loop methods is used (Secs. 104 and 106), the effect of the jumper at the end of the loop need not be considered.

142. In Locating An Open-Circuit Without Looping The Conductors By Means Of The Home-Made Fault Locator (Sec. 44), the connections are made as indicated in Fig. 105. When the resistance is so adjusted that the galvanometer shows no "kick" when the key, K , is closed to the lower contactor, the distance to the fault is computed by the following formula:

$$(27) \quad D = \frac{L}{2} \left(\frac{X}{100 - \frac{X}{2}} \right) \quad (\text{feet})$$

Wherein: D = distance, in feet, from point at which test is made to the open-circuit. L = length, in feet, of the line. X = scale reading. See the following derivation and example.

143. DERIVATION.—The capacity of the condenser (Fig. 105) which is formed by the conductor, G , is directly proportional to the length of the conductor. The same is true of the condenser which is formed by conductor F and ground. Furthermore, a given length of G will have the same capacity to ground as will the same length of F . For these reasons the total length, in feet, L of the good conductor and the length, in feet, D , to the "open" of the faulty conductor may be used in the Wheatstone-bridge formula (For. 16) instead of their respective capacities in microfarads. Also, by the same line of reasoning as that given in Sec. 118, the scale reading X , and $200 - X$ can be used in For. (22) instead of R_1 and R_2 , respectively. Therefore, when using the home-made fault locator as shown in Fig. 105, For. (22) may be written as:

$$(28) \quad \frac{X}{200 - X} = \frac{D}{L}$$

Or,

$$(29) \quad D = \frac{L X}{200 - X}$$

Which may be written as:

$$(30) \quad D = \frac{L}{2} \left(\frac{X}{100 - \frac{X}{2}} \right) \quad (\text{feet})$$

which is the same as For. (27).

144. EXAMPLE.—In testing to locate an open-circuit in an underground cable which is 9,700 ft. long, the home-made fault locator is connected as shown in Fig. 108. The cable is not looped at the end. The galva-

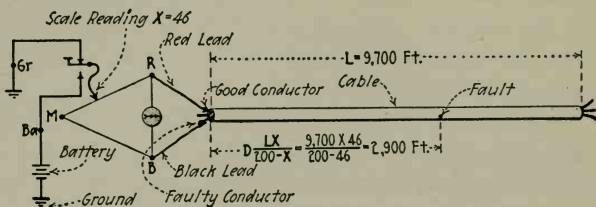


FIG. 108.—Illustrating one method of locating an open circuit with the home-made fault locator.

nometer balances with a scale reading of 46. How far is it to the fault?

SOLUTION.—By For. (27), the distance to the fault, $D = \left(\frac{L}{2} \right) \frac{X}{\left(100 - \frac{X}{2} \right)}$
 $= (9,700 \div 2) \times 46 \div (100 - 46 \div 2) = 4,850 \times (46 \div 100 - 23) =$
 $4,850 \times 46 \div 77 = 2,900 \text{ ft.}$

145. In Locating An Open-Circuit By The Home-Made Fault Locator With One Good Conductor Looped To The Faulty Conductor At The Far End, the connections are made as in Fig. 106, and the galvanometer is balanced by adjusting the slider until the galvanometer shows no deflection when the key, *K*, is closed to the lower contact. The distance measured along the cable from the instrument to the fault is computed by the following formula:

$$(31) \quad D = \frac{X}{100} L \quad (\text{feet})$$

Wherein: *D* = the distance, in feet, measured along the cable from the point of test to the open circuit. *X* = the scale reading. *L* = the length of the cable in feet. How this formula is derived is explained below.

146. DERIVATION.—The length of the conductor which is connected to *R* (Fig. 106) is equal to the total length of the line plus the length of

the faulty conductor back as far as the fault. That is, *the length of the conductor connected to R* $= 2L - D$ (see sec. 109). With this exception, the same line of reasoning applies as that given in Sec. 118. Therefore, by substituting the symbols which represent the different components of this circuit in the Wheatstone-bridge-circuit formula (For. 1), there results:

$$(32) \quad \frac{X}{200 - X} = \frac{D}{2L - D}$$

Or, clearing of fractions by multiplying For. (32) by $(2L - D)(200 - X)$,

$$(33) \quad 2LX - DX = 200D - DX$$

Transposing For. (33),

$$(34) \quad D = \frac{2LX}{200} = \frac{X}{100}L$$

which is the same as For. (31).

147. EXAMPLE.—In locating an open-circuit with one good conductor looped to the faulty conductor as indicated in Fig. 109, the galvanometer

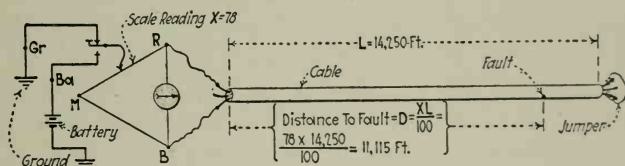


FIG. 109.—Illustrating a method of locating an open-circuit with the home-made fault locator by looping the faulty conductor to a good mate.

balanced at a reading of 78. The line was 14,250 ft. long. Where was the fault located? **SOLUTION.**—By For. (31), *the distance from the point of the test to the fault*, $D = \left(\frac{X}{100}\right)L = (78 \div 100) \times 14,250 = 0.78 \times 14,250 = 11,115 \text{ ft.}$

148. When Locating An Open-Circuit In A Three-Conductor Cable With The Home-Made Fault Locator By Looping The Faulty Conductor To A Good Conductor At Both Ends Of The Line, the connections are made as indicated in either Fig. 107 or Fig. 110. That is, one good conductor is looped to the faulty conductor at the far end of the line, and the other good conductor is looped to the faulty conductor at that end of the line where the test is to be made. Then, the fault locator is connected to one good conductor and the jumper, as indicated in Fig. 107 or Fig. 110. Whether the red-colored

lead of the instrument should be connected to the jumper (Fig. 107) or to the good conductor (Fig. 110) must be determined by trial. This is done by first connecting the instrument as shown in Fig. 107 and making a trial at balancing the gal-

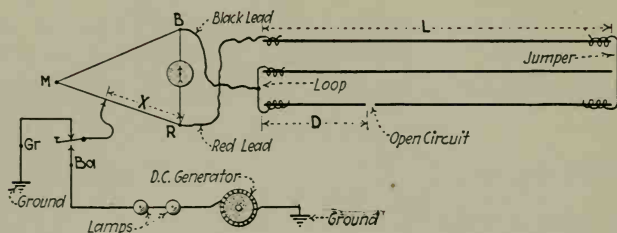


FIG. 110.—Diagram of connections for locating an open-circuit in a three-conductor cable by means of the home-made fault locator, when the distance to the fault is less than one-half the length of the line, with the faulty conductor looped to a good conductor at both ends of the line.

vanometer. If the galvanometer cannot be balanced, reverse the connection of the instrument leads, as shown in Fig. 110. If the distance (D , Fig. 107) to the open-circuit is greater than one-half of the length of the line L , the red-colored lead must, to obtain a balance, be connected to the jumper. If the distance (D , Fig. 110) is less than one-half the length of the line L , the red-colored lead must be connected to the end of the good conductor.

If a balance is obtained with the red-colored lead connected to the jumper (Fig. 107), the distance to this fault is given by:

$$(35) \quad D = \frac{L}{2} \left(4 - 3 \frac{X}{100} \right) \quad (\text{feet})$$

If a balance is obtained with the red-colored lead connected to the end of the good conductor, the distance to the fault is given by:

$$(36) \quad D = \frac{L}{2} \left(3 \frac{X}{100} - 2 \right) \quad (\text{feet})$$

Wherein: D = the length of the line, in feet. X the reading of the scale. When using this method of locating an open-circuit, the scale reading of the fault-finder will, if the instrument is constructed as outlined in Sec. 45, always be somewhere between 66.6 and 100. Also, to use this method, two of the three conductors must contain no fault. The derivation of each of these formulas is given below.

149. DERIVATION.—WHEN THE RED-COLORED LEAD IS CONNECTED TO THE JUMPER (Fig. 107), the length of the conductors which are connected to R is $L + D$, where L and D are, respectively the length of the line in feet, and the distance to the fault in feet. Also, the length of the conductors which are connected to B is $2L - D$. Then, by Sec. 143.

$$(37) \quad \frac{X}{200 - X} = \frac{2L - D}{L + D}$$

Or,

$$(38) \quad LX + DX = 400L - 200D - 2LX + DX$$

Transposing, For. (38) and changing signs.

$$(39) \quad 200D = 400L - 3LX$$

Or,

$$(40) \quad D = \frac{L}{2} \left(4 - 3 \frac{X}{100} \right)$$

Which is the same as For. (35).

150. DERIVATION.—WHEN THE RED-COLORED LEAD IS CONNECTED TO THE END OF THE GOOD CONDUCTOR (Fig. 110), the length of the conductors which are connected to R is $2L - D$, where L and D are, respectively, the length of the line in feet, and the distance to the fault, in feet. Also, the length of the conductors which are connected to B is $L + D$. Then by Sec. 143.

$$(41) \quad \frac{X}{200 - X} = \frac{L + D}{2L - D}$$

Or,

$$(42) \quad 2LX - DX = 200L + 200D - LX - DX$$

Transposing For. (42) and changing signs,

$$(43) \quad 200D = 200L - 3LX$$

Or,

$$(44) \quad D = \frac{3LX}{200} - L$$

Or,

$$(45) \quad D = \frac{L}{2} \left(3 \frac{X}{100} - 2 \right)$$

which is the same as For. (36).

151. EXAMPLE.—In locating an open-circuit on a 3-conductor cable which is 26,200 ft. long, it is found that a balance of the home-made fault locator is obtained with the red-colored lead connected to the loop (Fig. 111) when the scale reading is 75. How far is it to the fault? **SOLUTION.**—By For. (35), the distance from the point of test to the fault,

$$D = \frac{L}{2} \left(4 - 3 \frac{X}{100} \right) = (26,200 \div 2) (4 - 3 \times 75 \div 100) = 13,100 \times (4 - 2.25) = 13,100 \times 1.75 = 22,925 \text{ ft.}$$

152. EXAMPLE.—In locating a fault on the same line as that in Sec. 151, the fault locator balances at a scale reading of 75 when the red-colored lead is connected to the end of the good conductor, as in Fig. 110. How far is it from the point of test to the fault? **SOLUTION.**—By For.

(36), the distance from the point of test to the fault, $D = \frac{L}{2} \left(\frac{3X}{100} - 2 \right)$
 $= (26,200 \div 2) \times (3 \times 75 \div 100 - 2) = 13,100 (2.25 - 2) = 13,100 \times 0.25 = 3,275 \text{ ft.}$

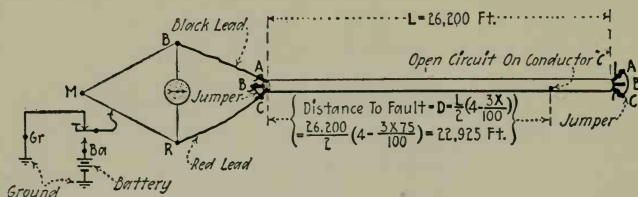


FIG. 111.—Example of locating an open circuit in one conductor of a three-conductor cable by connecting the red-colored lead of the home-made fault locator to the jumper.

153. In Locating An Open-Circuit In An Underground Cable With The "L. & N. Power Bridge" (Sec. 46), the connec-

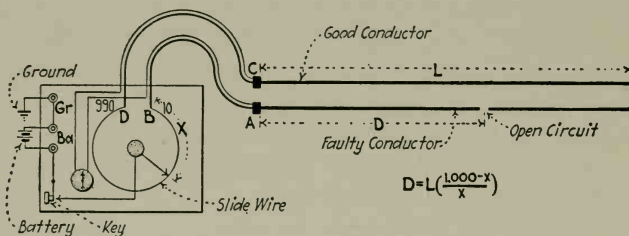


FIG. 112.—Diagram of connections for locating an open-circuit in an underground cable with the "L. & N. Power Bridge" without loop.

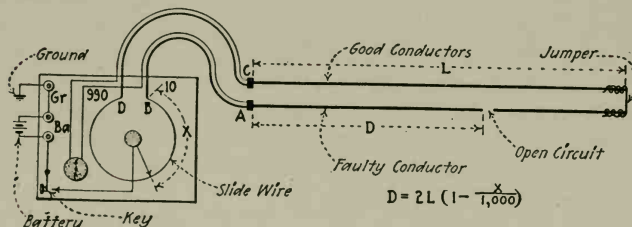


FIG. 113.—Diagram of connections for locating an open-circuit in an underground cable with the "L. & N. Power Bridge" by looping one good conductor to the faulty conductor at the far end of the line.

tions should be made as shown in Figs. 112, 113, and 114. That is, if only two conductors are used (Figs. 112 and 113), connect the instrument lead, CD, from the "990" side of the

scale to the good conductor, and connect the instrument lead, *AB*, from the "10" side of the scale to the faulty conductor. If the three conductors are being used (Fig. 114) connect the lead, *CD*, from the "990" side of the scale to the free end of the

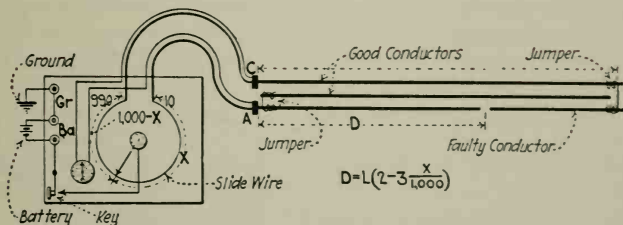


FIG. 114.—Diagram of connections for locating an open-circuit in a three-conductor cable with the "L. & N. Power Bridge" by looping a good conductor to the faulty conductor at each end of the line. To use this method, two of the conductors of the cable must be without fault.

good conductor, and connect the lead, *AB*, from the "10" side of the scale to the loop. After each galvanometer observation, touch a grounded wire to each test clip of the instrument leads to discharge the conductors. The reason this must be done is because the instrument is not provided with a double-contact key as is the home-made fault locator (Sec. 45). With the connections made as indicated above, the location of the fault is computed as follows:

If the conductors are not looped together (Fig. 112):

$$(46) \quad D = L \left(\frac{1,000 - X}{X} \right) \quad (\text{feet})$$

If the faulty conductor is looped to a good conductor at the far end of the line (Fig. 113):

$$(47) \quad D = 2L \left(1 - \frac{X}{1,000} \right) \quad (\text{feet})$$

If the faulty conductor is looped to a good conductor at both ends of the line (Fig. 114):

$$(48) \quad D = L \left(2 - 3 \frac{X}{1,000} \right) \quad (\text{feet})$$

Wherein: *D* = the distance, in feet, measured along the conductor from the point of test to the fault. *L* = the length of the line, in feet. *X* = the reading of the scale when the in-

strument is balanced. The derivation of these formulas is given below.

154. DERIVATION.—The reading X of the scale of an "L. & N. Power Bridge" (Fig. 44) is proportional to the resistance in one arm of the bridge (Fig. 103). Since the full-scale reading is "1,000," it follows that $1,000 - X$ is proportional to the resistance in the other arm of the bridge. The conductor length which is connected to each of the resistance arms of the bridge is proportional to the capacity in that arm. In Fig. 112, *where the faulty conductor is not looped to the good conductor, the length of the good conductor* which is connected to the " $1,000 - X$ " resistance arm of the bridge is equal to the length of the line, or L . The length of conductor which is connected to the " X " arm of the bridge is equal to the distance, D , to the fault. Therefore, by Sec. 136:

$$(49) \quad \frac{X}{1,000 - X} = \frac{L}{D}$$

which if simplified, takes the form as given in For. (46).

In Fig. 113, *where the faulty conductor is looped to the good conductor at the far end of the line*, the length of conductor which is connected to the " $1,000 - X$ " resistance arm is $2L - D$. The length of conductor which is connected to the " X " resistance arm of the bridge is the distance D from the bridge to the open circuit. Hence, by Sec. 136:

$$(50) \quad \frac{X}{1,000 - X} = \frac{2L - D}{D}$$

which if simplified takes the form of For. (47).

In Fig. 114, *where the faulty conductor is looped to a good conductor at each end of the line*, the length of conductor which is connected to the " $1,000 - X$ " resistance arm is $2L - D$. The length of conductor which is connected to the " X " resistance arm is $L + D$. Therefore by Sec. 136:

$$(51) \quad \frac{X}{1,000 - X} = \frac{2L - D}{L + D}$$

Which when simplified takes the form of For. (48).

155. EXAMPLE.—In locating an open-circuit on a two-conductor underground cable with an "L. & N. Power Bridge," a balance is obtained at a scale reading of 653. The connections are made as in Fig. 112, without looping the conductors. The line is 16,800 ft. long. How far from the instrument is the fault?

SOLUTION.—By For. (46), *the distance to the fault*, $D = L \frac{(1,000 - X)}{X}$
 $= 16,800 (1,000 - 653) \div 653 = (16,800 \times 347) \div 653 = 8,927 \text{ ft.}$

156. EXAMPLE.—In locating the same fault as in Sec. 155, the faulty conductor was looped to the good conductor at the far end of the line as shown in Fig. 113. The scale reading, when the bridge was balanced, was 735. Compute the distance to the fault. **SOLUTION.**—By For. (47),

the distance to the fault, $D = 2L \left(\frac{1 - X}{1,000} \right) = 2 \times 16,800 (1 - 735 \div 1,000) = 33,600 \times 0.265 = 8,904 \text{ ft.}$

157. EXAMPLE.—In order to locate an open-circuit in a three-conductor underground cable, one good conductor was looped to the faulty conductor at the far end of the line and the other good conductor was looped to the faulty conductor at the instrument as shown in Fig. 114. The cable was 24,750 ft. long. The "L. & N. Power Bridge" balanced at a reading of 448. How far was it from the instrument to the fault?

SOLUTION.—By For. (48), the distance to the fault, $D = L \left(\frac{2 - 3X}{1,000} \right) = 24,750(2 - 3 \times 448 \div 1,000) = 24,750(2 - 1.344) = 24,750 \times 0.656 = 16,236 \text{ ft.}$

158. The Relative Advantages And Disadvantages Of The Three Different Methods Of Connections For Locating Open-Circuits, which are outlined in Sec. 140, may be stated thus: When there are two good conductors in the same cable as the faulty conductor, looping both ends of the line together, as explained in Sec. 148, will ordinarily be the most accurate. The reason for this is because the ratio between the capacities (Sec. 136) in the two capacity arms of the bridge cannot be greater than 2:1, whereas in either of the other two methods this ratio may be anything. However, the formulas for the two-loop method are somewhat complicated and difficult to remember. Furthermore, it will very seldom happen that one conductor of a three-conductor cable will burn in two without causing a fault on at least one of the other conductors. Where only one good conductor is available, the method without the loop (Sec. 142) will ordinarily give more accurate results than will the method (Sec. 145) where the conductors are looped together. However, when the home-made fault locator is used, on account of the simplicity of the formula (For. 31) which applies, the method wherein the two conductors are looped together (Fig. 106) is ordinarily employed.

159. In Locating Faults By The Tone-Test Method (Fig. 115) a varying current is sent through the faulty conductor to the fault. The varying current which is thus sent through the conductor, for the purpose of locating the fault, is called the *fault current* or *tracing current* (Sec. 226). An exploring coil (Secs. 53 to 55) which is connected to telephone receivers is carried by the troubleman along the route of and as close as is

feasible to the faulty conductor. The fault current induces an electromotive force in the exploring coil which causes a varying current to flow through the receiver. The sound which is thereby produced can be heard in the receiver by the person who is hunting the fault. After the location of the fault is passed there will, theoretically, be no fault current to energize the exploring coil and telephone receiver. Hence, the sound cannot be heard. In this manner the position of the fault is located.

160. Those Faults Which May Be Located By Tone Test Are Grounds And Short-Circuits.—See the following sections.

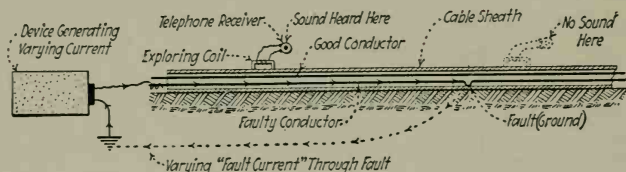


FIG. 115.—Illustrating the principle of fault location by the tone-test method.

In locating a ground, the faulty conductor (Fig. 115) and the earth or cable sheath form the circuit through which the fault current flows. In locating a short-circuit (Fig. 116),

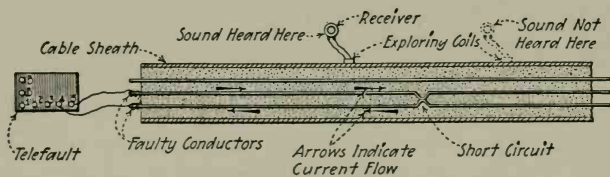


FIG. 116.—Circuit diagram for locating a short-circuit in a cable with the Matthews Telefault.

the two faulty conductors make the circuit for the fault current. An open-circuit cannot be located by ordinary tone-test methods.

161. In Testing To Locate A Ground In An Underground Cable With The Telefault (Sec. 49) the connections are made as indicated in Fig. 117. That is, terminal No. 4 (Fig. 117) is connected to the grounded conductor and terminal No. 5 is connected to the sheath of the cable. The vibrator is started

and the exploring coil is placed against the cable in the manholes (Sec. 170) as shown in Fig. 58. After the fault has been passed (Fig. 117) no sound should be heard in the receivers.

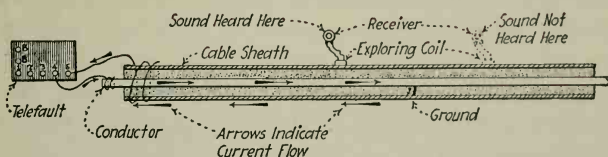


FIG. 117.—Illustrating method of locating a ground with the Matthews Telefault.

162. To Locate A Short-Circuit In A Multi-Conductor Cable With The Matthews Telefault, terminals Nos. 4 and 5 on the instrument are connected to the faulty conductors as shown in Fig. 116. The location of the short-circuit is determined in the same manner as that which is described in Sec. 161 for a ground.

163. In Locating A Fault With The Queen Wireless Test Set (Sec. 50) the instrument is connected to the faulty circuit, and the exploring coil is placed flat against the cable sheath at manholes. In locating a ground (Fig. 118), terminal No. 2 is

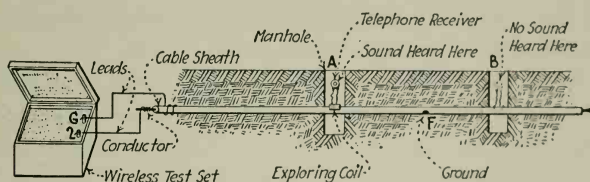


FIG. 118.—Method of locating a ground with the Queen Wireless Test Set.

connected to the grounded conductor and terminal *G* is connected to the cable sheath. In locating a short-circuit the connections are made the same as for locating a ground, except that terminal *G* is connected to one of the faulty conductors instead of to the cable sheath. As indicated at *A*, Fig. 118, when the exploring coil is between the fault and the instrument the sound will be heard in the receivers. When the fault has been passed *B*, (Fig. 118)—the fault between the instrument and the exploring coil—no sound should be heard.

164. The Faults Which May Be Located By The Lundin Fault Locater (Sec. 51), as stated by the manufacturer are: (1) *Carbonizing high-resistance faults.* (2) *Line crosses on street-circuits.* (3) *Street-circuit crossed with direct current.* (4) *Opens on street-circuits, overhead lines and underground cables.* (5) *Grounds and short-circuits on overhead lines and underground cables.* (6) *Faults on direct-current network.* (7) *Leaky insulators on pole lines.* The methods of analyzing a fault to determine its nature and its location with this instrument are contained in *Instruction Book No. 1021*, which is published by THE LUNDIN ELECTRIC & MACHINE Co., Boston, Mass. and which is furnished with each instrument.

165. NOTE.—IN LOCATING A FAULT BY THE TONE-TEST METHOD, the exploring coil should always be applied to the cable at a point near the instrument before the searcher goes out on the line. The reasons for this are: (1) *To insure that the instrument is functioning properly and is sending a current over the faulty conductors.* (2) *So that the searcher may obtain an accurate idea of the sound for which he is to listen when he gets out on the line.* This may be done by applying the exploring coil to the cable at some point in the station which is at least a few feet from the place where the instrument is connected. In the event that such an exposed portion of the cable is not readily available within the station, make the preliminary test at the first manhole outside of the station.

166. Ordinarily, The Quickest And Most Accurate Method Of Locating A Fault On Underground Cable is to locate the fault as accurately as is possible by a resistance measurement (Secs. 103 to 131). Then connect some kind of a tone-test instrument to the line, go out on the line and listen in with the exploring coil at the two manholes adjacent to the location as determined by the resistance measurement. Thus, if the computations from the resistance measurements show the fault to be located at *F* (Fig. 118) listen in with the exploring coil at manholes *A* and *B*. By this means each method will serve as a check on the other. Furthermore, resistance measurements can be made in a short time and will ordinarily give fairly accurate results, but the result may in some cases be in error by one or two manholes. If the two methods are used, it will generally eliminate the necessity of traveling over a considerable portion of the line, opening several manholes (Sec. 117), and possibly a few false cuts.

167. NOTE.—IN LOCATING A FAULT ON A CABLE BY THE TONE-TEST METHOD WHEN ONE HAS NO IDEA AS TO WHERE THE FAULT IS, proceed as indicated in Fig. 119. This is called “halving the distance.” Thus, a cable 8 miles long connects substation A to substation B. The tone-test instrument is connected at substation A. Make the first test,

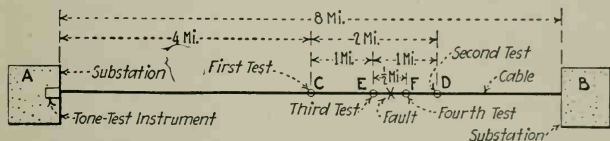


FIG. 119.—Illustrating locations at which tests are made in locating a fault by the tone-test-method.

at one-half the distance between the substations, at manhole C which is 4 miles from A. At C the sound is heard, which indicates that the fault is somewhere between C and B. Next go to D which is 2 miles from C, or one-half of the distance between C and B. At D no sound is heard, thus indicating that the fault is between C and D. Next go to E which is 1 mile back from D, or one-half the distance between D and C. Continue in this manner, by making each test at a point half way between the last two tests made, until the fault is located between two adjacent manholes. It will be seen that on an 8-mile length of cable, 7 tests should locate the fault between two points $\frac{1}{16}$ mile or 330 ft. apart.

168. The Two Principal Effects Which Cause Errors In Locating Faults By The Tone-Test Method are (1) *Sheath Current* (Sec. 169). (2) *Electrostatic Capacity* (Sec. 174). How each of these effects are likely to cause erroneous results, and how each effect may, to a certain extent, be eliminated are explained hereinafter.

169. The Sheath Current is the fault current (Sec. 159) which returns to the test-set instrument through the sheath of the cable or through the earth in locating a ground. If all of the fault current passed from the conductor to the sheath and returned directly to the instrument, the sheath current would cause no trouble in locating grounds. However, what generally happens is indicated in Fig. 120. That is, the fault current divides at the fault. A part of it goes on down the sheath and spreads out through the earth in returning to the test set. Consequently, when the exploring coil is held at A, a sound is heard. This indicates that the fault is farther on, when in reality it has already been passed.

170. NOTE.—IF IN A DUCT THERE ARE SEVERAL CABLES WHICH ARE BONDED TOGETHER, THE EFFECT OF THE SHEATH CURRENT MAY BE MISLEADING IN LOCATING A FAULT. Thus, in Fig. 121, the fault current divides at the grounded point, *G*, and returns through the two

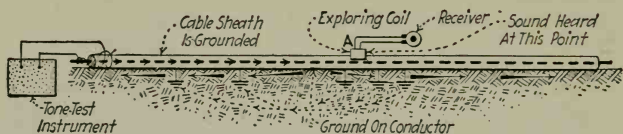


FIG. 120.—Illustrating how the sheath current may divide at the fault and result in an error in locating the fault. Arrows indicate current paths.

paths as indicated by the arrows. Consequently, a sound will be heard when the exploring coil is at *C*. When such conditions exist, the exploring coil should always be applied to the cable on each side of the bonds. If the sound is heard on both sides of each bond, (*A* and *B*, Fig. 121), the fault is farther away from the test instrument. If the sound is heard only on one side of a bond, *C*, and not on the other side, *D*, the fault has been passed and is closer to the tone-test instrument than is the tester.

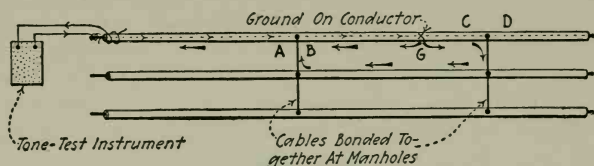


FIG. 121.—Illustrating how bonded cables may cause the sheath current to give erroneous indications in locating a ground. Arrows indicate current paths.

171. The Effect Of Sheath Current In A Multi-Conductor Cable Can Ordinarily Be Detected as follows: Only one cable conductor (Fig. 120) is connected to the tone-test instrument. Use a sector-type exploring coil (Fig. 54), and make each test by moving the coil entirely around the cable (Fig. 122) from *A* to *B* and back to *A*. If the intensity of sound varies as the coil is moved around the cable, that is, if it is louder in one position than in another, the variation in sound is caused by the combined flux due to the fault current in the conductor and the sheath current in the sheath. Hence, if the sound changes, as the coil is moved around the cable, this indicates that the exploring coil is between the tone-test instrument, which generates the tracing current, and the fault.

If the intensity of the sound does not change, as the exploring coil is shifted to different positions around the cable, the sound is produced by sheath current alone, which means that the fault is between the exploring coil and tone-test instrument.

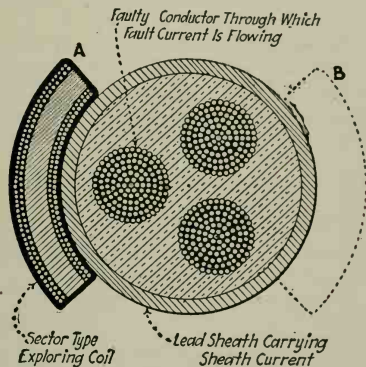


FIG. 122.—Using a sector type exploring coil, the volume of sound will vary as the coil is moved around a three-conductor cable, if the coil is between the fault and the tone-test instrument.

172. In Locating A Ground In A Single-Conductor Cable By The Tone-Test Method, the sheath current may be utilized to aid in locating, by the use of a copper shunt, *S*, as indicated

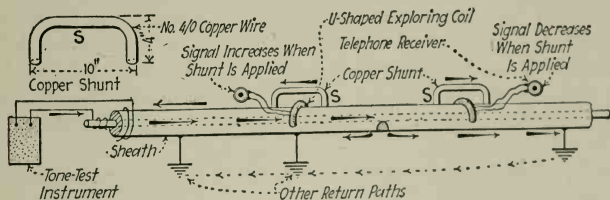


FIG. 123.—Using a copper shunt to assist in locating a fault in a single-conductor cable.

in Fig. 123. The copper shunt is made from a piece of No. 0000 copper about 20 in. long which is bent into a U-shape about 4 in. high and 10 in. long. In searching for the fault, the exploring coil is laid over the cable and the intensity of sound noted. The shunt is then placed on the cable over the exploring coil as shown in Fig. 123. If the sound increases when the shunt is applied, the exploring coil is between the

tone-test instrument and the fault. If the sound decreases when the shunt is applied, the fault is between the exploring coil and the tone-test instrument. It is essential that the copper shunt make good electrical contact with the lead sheath of the cable, or no change in sound can be noted.

173. NOTE.—A METHOD OF LOCATING GROUNDS IN BURIED LEAD-COVERED POWER CABLES (Fig. 124) was developed by H. S. BAKER, of the Ontario Power Company, Niagara Falls, Canada, and is described in *Electrical World*, Vol. 82, No. 16, p. 815:

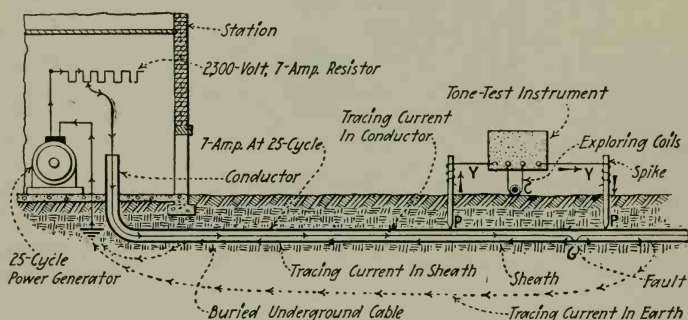


FIG. 124.—Schematic general diagram of H. S. Baker's arrangement for locating faults.

The cable system for which this method was developed and upon which it was used, was a group of four-wire, three-phase, 25-cycle feeders. The voltage to neutral is 2,300 volts. Each feeder consists of three No. 6 single-conductor lead-sheath cables buried in a trench about 18 in. deep, with their lead sheaths in direct contact with the soil. Each feeder is about 10 miles long and is divided in sections of 1 mile to 3 miles each.

The 25-cycle tracing current is obtained from the station bus by inserting a 2,300-volt, 7-amp. Nichrome-wire current-limiting resistor in series in the tracing circuit. This resistor was mounted in a wooden frame 3×5 ft. in size and was composed of No. 22 Nichrome wire with springs to keep the wires tight as they expanded on heating.

The fault-locating device is so designed that it operates by virtue of: (1) *The magnetic field which is produced by the tracing current.* (2) *The potential drop of the tracing current along the cable sheath.* How each of these factors is utilized is shown in Fig. 124. The exploring coil (*C*, Fig. 124), which is laid on the ground over the cable is affected by the magnetic field which is produced by the tracing current.

After the tracing current leaves the faulty conductor at the accidental ground, *G* (Fig. 124) it returns along the cable sheath. Therefore, there

will be a potential difference between any two points P and P along the sheath. By driving spikes into the ground alongside of the cable sheath at P and P , this potential difference is impressed on the spikes, thereby causing a current to flow through the instrument via conductors Y and Y , which are (Fig. 124) connected to the spikes. Thus, the effect of the potential drop of the tracing current along the cable sheath is communicated to the testing instrument.

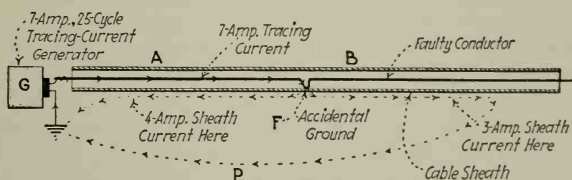


FIG. 125.—Illustrating how the magnetic effect of the fault current may be the same on each side of the fault.

The reason why both of the above-mentioned effects must be considered in locating a ground is as follows: In Fig. 125, it is assumed that the generator G is forcing a tracing current of 7 amp. through the fault F .

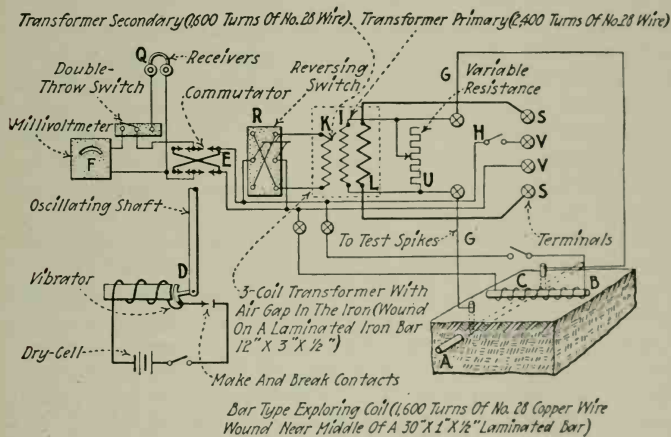


FIG. 126.—Schematic wiring diagram of apparatus for locating faults in a buried cable, as arranged for determining the approximate position of a fault. (H. S. Baker of the Ontario Power Company, Niagara Falls, Canada in *Electrical World*, Vol. 82, No. 16, p. 815.)

At F , this 7-amp. tracing current so divides that 4 amp. returns through the sheath to the left of F , and the other 3 amp. ($4 + 3 = 7$) goes on down the cable and spreads out into the ground and returns via path P . On the left of F , as at A , there is 7 amp. flowing to the right and 4 amp.

to the left. Therefore, there is: $7 - 4 = 3$ amp. which is effective in producing a magnetic flux through one exploring coil at *A*. Also at *B*, there is a current of 3 amp. which is effective in producing a magnetic flux through an exploring coil. Therefore, with a condition such as that of Fig. 125, it cannot be determined by an exploring coil alone when the fault has been passed.

The diagram of connections of the testing instrument is shown in Fig. 126. The windings (*I*, *K*, and *L*) of the three-coil transformer are wound on an iron core. The secondary, *K*, of this transformer is connected to a double-pole double-throw reversing switch, *R*. The other terminals of *R* are connected to the four-contact commutator, *E*. The two terminals of the exploring coil, *C*, is also connected to the same terminals of *E*. A direct-current millivoltmeter, *F*, is connected to the outgoing terminals of this commutator. The commutator, *E*, is actuated by an oscillating shaft, *D*. This shaft is caused to oscillate by a make-and-break vibrator, which is operated by a single dry cell, *T*. The rate of vibration of the vibrator, and consequently the rate oscillation of the commutator *E*, is adjustable in the neighborhood of 25 cycles. Thus if the vibrator vibrates at about 24.5 cycles per second while a 25-cycle electromotive force is impressed on *E*, the direction of current flow through the direct-current millivoltmeter, and consequently the needle swing, will reverse about once in each second. The length of the arc through which the needle will swing will be proportional to the voltage which is impressed on the millivoltmeter. Hence, if switch *R* is closed to one position and the voltages due to the potential drop along the cable sheath and that due to the magnetic effect of the fault current are additive, then in the other position they will be subtractive. Consequently, the needle will have a longer swing when the switch *R* is closed to one side than it will when *R* is closed to the other side. This is the indication, as explained below, whereby the fault is located.

When a ground develops on a feeder, its approximate location is, when possible, determined by means of resistance measurements (Secs. 103 to 131). Then the 7-amp. 25-cycle fault current is fed into the faulty conductor (Fig. 124). Next, the above-described fault-locating instrument is taken to the point previously determined by resistance measurements. Two $\frac{3}{4}$ -in. diameter iron spikes (*PP*, Fig. 124) are driven into the ground to a depth of about 18 in. alongside the cable, and about 150 ft. apart. These two spikes are connected to *GG* (Fig. 126).

The exploring coil, *C*, is laid on the ground (over the cable, *A*) and with its core, *B* at right-angles to the direction of the cable. The swing of the millivoltmeter needle is noted. Then close switch *R* to the other side. If the needle is the same as before *R* was reversed, the fault lies somewhere between the two spikes. If the needle swing is longer with the switch in one position than with it in the other, the fault is either beyond or back of the two spikes. The direction in which to go to make the next test—away from or toward the station—must be previously determined by experimenting on a fault of known location, and by placing the

necessary markings on the reversing switch and on the instrument terminals.

The above method is accurate to within a distance of only 100 to 150 ft. When the fault has been localized to within this distance, the earth is dug away so as to bare 2 or 3 ft. of cable sheath. The small U-shaped exploring coil (*M*, Fig. 127) is placed over the cable and its terminals connected to *VV*. The test spikes, *PP*, are now touched to the cable sheath at points on each side of *M* about 2 ft. apart, and connected to *SS*. Close switch *H* and adjust *U* so that the millivoltmeter-needle swing is a maximum. Now by reversing *R*, the direction of the fault from the

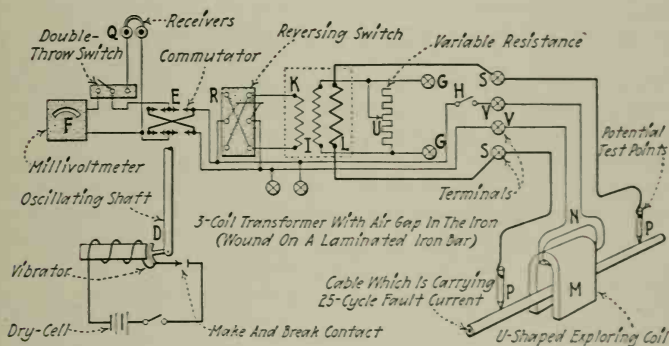


FIG. 127.—Schematic wiring diagram of apparatus for locating faults in a buried cable, as arranged for determining the exact position of a fault.

position of test is determined in the same manner as explained above. The receiver, *Q*, may be used instead of the millivoltmeter, the increase, decrease, or constant sound by reversing *R* determining the direction of the fault just as by the change in the needle swing explained above.

With the coil *M*, the fault can be located to within a few inches of its exact position. Care must be taken to avoid mistaking a good cable, which is carrying load, for the faulty cable which is under test; this confusion may occur where more than one cable is buried in one trench. It will usually save time and confusion to cut the load from all of the other cables which are in the same trench with the cable which is under test.

174. When Locating A Fault By The Tone-Test Method, The Effect Of The Capacity Of An Underground Cable frequently results in the sound being heard at locations a considerable distance beyond the fault. This is especially true if the fault has a high resistance, and if the fault current is of high frequency. Thus, if a ground has such a great resistance that

a relatively high voltage must be applied to obtain sufficient fault current to produce an audible sound in the receiver, the charging current will frequently be sufficient that it can be heard throughout the entire length of the line. Sometimes the volume of the sound will decrease sufficiently after passing the fault that the location of the fault can be detected, and sometimes it will not. Under such conditions, it is very difficult, and sometimes impossible, to locate the fault by using ordinary tone-test apparatus. In the following note is described a method which by the use of direct-current fault current practically eliminates the capacity effect.

175. NOTE.—THE USE OF DIRECT CURRENT FOR LOCATING FAULTS ON UNDERGROUND CABLES is described by W. R. BULLARD, in *Electrical World*, Nov. 27, 1920, pp. 1057-60, as follows:

The ideal current for use as tracing current is that which involves no change of value, or, in other words, direct current. But where a direct-current tracing current is used it is obvious that some method of detection

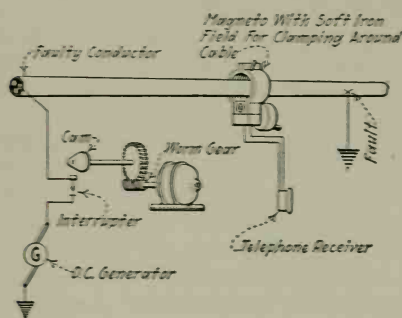


FIG. 128.—In this method of fault location the direct current from the direct-current generator, *G*, through the faulty conductor produces the field excitation for the magneto.

other than the ordinary exploring coil must be employed. A method of detection for use with direct current has been developed. The elements of this method are shown in Fig. 128.

Direct current is applied to the faulty conductor in a manner similar to that which is used with an alternating tracing current. An interrupter is inserted, but the period of interruption is very slow, being in the neighborhood of 2 sec. for each complete cycle. That is, the cycle consists of a period of 1 sec. on and 1 sec.

off. It has been found that with this period of interruption the capacity effect of the cable is entirely negligible, and no matter how high the resistance of the fault may be, no tracing current can be detected by ordinary methods in the conductor beyond the fault. Except perhaps a click in the telephones at the instant of making or breaking the circuit.

The principal element of this system is the detecting instrument Fig. 128. Basically, this is a generator, either alternating current or direct current, which has a field comprising two halves of soft iron (Fig. 129). This field is arranged to clamp around the cable. The armature

is revolved with a crank and gears. The resulting e.m.f. is impressed upon a telephone receiver. The field is excited by the direct current which passes through the grounded conductor of the cable. The object of the periodic interruption of this current is to enable the observer to distinguish between the effects of residual magnetism in the field pieces of the detecting instrument (or stray fields in the vicinity) and the field

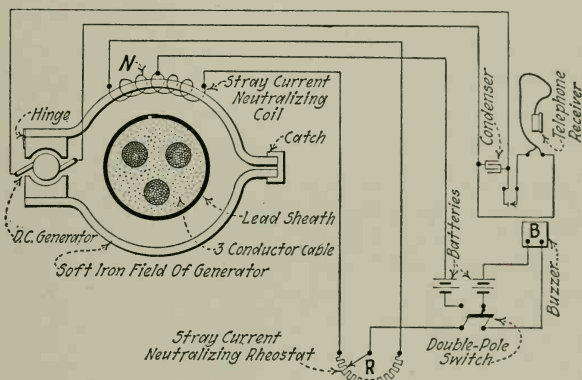


FIG. 129.—Detecting apparatus, employing a "Stray-current Neutralizing Coil," which is used when the fault current is of low value.

produced by the tracing current which flows through the grounded conductor. Thus, though the observer may constantly hear a sound in the telephones due to residual magnetism or stray fields, also he can detect periodic variations in sound in the receiver which are due to the interrupted tracing current through the faulty conductor.

The simple apparatus, shown in Fig. 128, will produce comparatively good results in cases where a direct current of 6 amp. or 8 amp. can be obtained through the fault. However, it is in certain cases impossible to obtain a current of this magnitude at ordinary voltages, owing to the fact that in these cases the resistance of the fault is comparatively high. To detect currents of smaller than 6 or 8 amp., it has been found necessary to make certain additions to the detecting instrument. A diagram of the complete instrument, using a telephone receiver as the indicator, is given in Fig. 129. The generator has a comparatively low speed and, if slip rings were used, would produce about a 15-cycle alternating current when the crank is turned at a moderate rate. Instead of slip rings, a two-segment commutator is employed. This produces a unidirectional electromotive force with a corresponding frequency of pulsation. The peaks of this electromotive force are smoothed out by means of a condenser, *C*.

Since the frequency of 15 cycles or 30 pulsations is too low for good audibility, a buzzer interrupter, *B*, which is operated by a small battery,

has been added to make and break the telephone circuit. In addition to this, a coil, *N*, (Fig. 128) for neutralizing the residual magnetism or the stray fields which are due to direct current flowing through the sheath of the cable, has been added. This coil, *N*, is excited from a battery similar to the one which operates the buzzer; the current through it is adjusted by a rheostat, *R*. By means of the coil and rheostat, a flux which is passing, in either direction, through the field pieces of the instrument, can be neutralized, if it is constant.

When testing, the procedure is first to clamp the instrument around the cable and then to revolve the generator armature and listen for constant

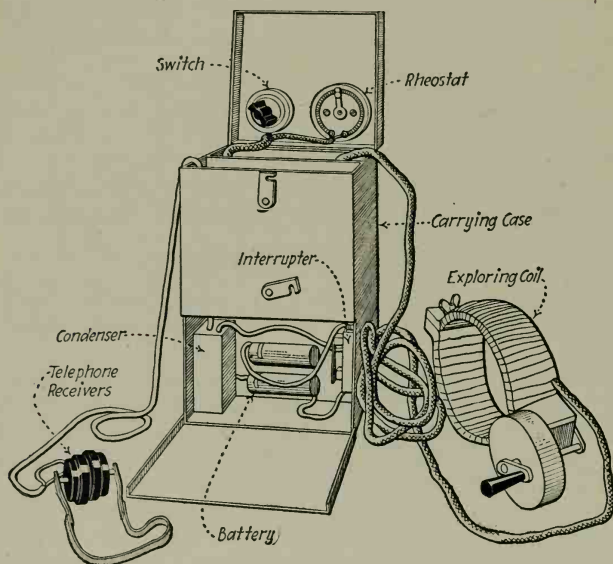


FIG. 130.—Assembly of detector set for locating, with direct current, faults on buried cables.

sound in the telephones. The rheostat is then adjusted so that minimum *constant* sound will be produced. As soon as this is done the periodic rise and fall of sound due to the tracing current can be heard. It will be noted that the same switch which is used to open the buzzer circuit, also opens the neutralizing-coil circuit. This provides against leaving the neutralizing circuit closed and thereby exhausting the battery, for the buzzer will give a warning sound until the circuit is opened.

The complete outfit (Fig. 130) is contained in a sheet-metal case, which also provides mounting for the switch, rheostat, batteries and buzzer. The inside diameter of the field pieces when closed is approximately 6 in., which permits the apparatus to be clamped around a three-conductor

cable which has a protective covering of cement. The gears are inclosed in a protective case of sheet brass. The buzzer is mounted on leather straps in the lower part of the case to reduce noise. With an outfit of this type it is practical to detect tracing currents of the order of 2 amp. or 3 amp. As an indicator the telephone receiver has the advantage of simplicity, ruggedness and sensitivity. However, its use involves several objectionable features, as enumerated below:

1. *It is practically impossible to reduce the constant sound in the receivers to zero. This is due to the fact that while it is possible to reduce the average value of unidirectional current to zero, still, owing to local magnetic circuits in pole faces and residual magnetism in the armature itself, a certain amount of fluctuating current will remain in the telephone circuit, regardless of the position of the neutralizing rheostat.*

2. *The use of telephone receivers does not provide an exact measurement of the amount of tracing current. It is important to obtain such measurement because of the presence of tracing current flowing along the sheath of the cable, as will be shown further on.*

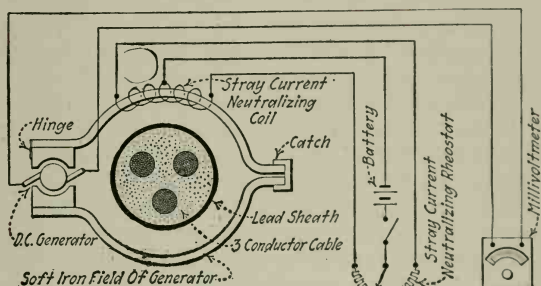


FIG. 131.—By using a millivoltmeter instead of telephone receivers, a more positive indication of fault current is obtained.

3. *When telephone receivers are used, the stray-current neutralizing coil N , does not eliminate sound which is caused by stray alternating current in the cable sheath or by stray alternating fields. The elimination of this sound is effected to some extent by the condenser which is shunted across the armature terminals. But it is impossible entirely to neutralize stray alternating current of a certain character without the use of condensers of large size, which would make the apparatus cumbersome.*

These telephone-receiver difficulties are overcome (Fig. 131) by using a direct-current millivoltmeter as an indicator instead of the telephone receivers. The moving element of a millivoltmeter cannot follow the fluctuations of induced alternating currents of the usual frequencies nor the fluctuations produced by the revolving armature of the instrument. Hence the millivoltmeter needle gives true indication of the average unidirectional-current value; disturbances produced by stray alternating fields are entirely eliminated. Furthermore, the swings of the milli-

voltmeter needle, which are due to the periodic application of tracing current, give a fairly accurate indication of the amount of tracing current which is flowing through the cable. The amount of indication varies somewhat with the speed at which the crank of the instrument is turned, but it is not necessary to time this speed accurately to obtain a degree of accuracy which is sufficient for practical purposes.

To use the detector set with a millivoltmeter as an indicator, the instrument is clamped around the cable, the armature is revolved and the stray-current neutralizing rheostat adjusted until the average indication of the needle is in the neighborhood of zero. The millivoltmeter should be one which has its zero point at the center of the scale. After the rheostat is adjusted, the observer continues to turn the crank. If he is between the point of application of tracing current and the fault, the needle of the millivoltmeter will periodically swing first to one side of zero and then the other, following the periodic application and removal of the tracing current which is effected by the motor-driven interrupter. If he has passed the fault the millivoltmeter needle will not swing at all.

The instrument shown in Fig. 131 can, without difficulty, be constructed for almost any degree of sensitivity. In fact, it can be constructed to detect direct currents of the order of a small fraction of an ampere. The sensitivity is only a question of size and material of the generator pole pieces, the winding of its armature, the speed of the armature and sensitivity of the millivoltmeter. In practice, the limiting factor has been found to be the effect of stray fields and stray direct current in the sheath of the cable. A stray field of practically any value, can, if constant, be neutralized by adjusting the stray-current neutralizing coil. However, under the conditions which are ordinarily encountered, there are always fluctuations in stray fields and in stray current. These may be due to changes in load on adjacent circuits which are carrying direct current, to changes in stray ground currents due to passing trolley cars, and to other causes such as these.

Under conditions such as are encountered in the business districts of New York City, it has been found that the fluctuations of stray current will be of such magnitude as to render the indication of tracing current somewhat uncertain, if the value of the tracing current is reduced to less than approximately 1 amp. However, in certain cases, a current as low as 0.5 amp. has been used. In the majority of cases it is not difficult to obtain 1 amp. or more through the fault with a direct-current voltage of 120. If the resistance of the fault is of such value as to limit the tracing current to less than 1 amp., it is usually possible to decrease the resistance of the fault (Sec. 95) by applying high potential for a short length of time and thereby burning the fault to a lower resistance. If the interrupter shown in Fig. 128 be replaced by a reversing switch, and if the current be reversed at each operation of the switch, instead of interrupted, the effect on the millivoltmeter of Fig. 131 will be doubled, reducing the amount of tracing current which is required for positive operation to 0.5 amp. instead of 1 amp.

Occasionally, a fault is encountered the resistance of which is so high that, at ordinary direct-current voltages, it limits the tracing current to a small fraction of an ampere, and furthermore it is practically impossible to reduce the resistance of the fault by "burning" it with high potential. In such cases it is usually impossible to locate the fault with the apparatus which is described above, without certain modifications. In such cases the fluctuations which are due to stray currents are of sufficient magnitudes to drown out those which are due to the tracing current. However, the effects of the stray currents can be considerably reduced by "tuning" the millivoltmeter to correspond with the period of the applied tracing current. The fluctuations caused by stray current will then remain constant, while those caused by the tracing current can be multiplied many times. The details of the tuned method are as follows:

The millivoltmeter must be devoid of all damping so that its moving element will swing freely, with a natural period of about 1 or 2 sec. A meter of this type can be very easily constructed from an ordinary D'Arsonval type of millivoltmeter by rewinding the moving element on a frame of non-metallic material. Provision must be made for adjusting the period of the instrument. This may be effected by changing the length of the spring, by moving adjustable weights toward or from the pivot of the moving element, or by some other similar means. The interrupter must have an absolutely constant period, which need not, however, be adjustable. In cases where an alternating-current supply which has very close frequency regulation is available, this can be accomplished by using a synchronous motor to drive the interrupter. Another alternative is the use of a pendulum contact. This method is under development at present; its effectiveness is not yet known. However, in the laboratory, it has been possible to increase the millivoltmeter indications by 80 or 90 times by applying a twisting current which had the same frequency as the natural period of oscillation of the voltmeter movement. It is believed that, after this "natural-frequency" method has been fully developed, it will (under the usual stray-current interference conditions) be possible to detect a periodic tracing current of the order of a very small fraction of an ampere.

In the case of ungrounded high-tension circuits where single-conductor cable is used, quite frequently one conductor may become grounded without affecting the other conductors. In such cases (on distribution circuits, for example) it may be desirable to keep the circuit in service while locating the fault. The direct-current tracing-current method of fault location offers a very suitable means for locating a fault of this kind. If the connections in Fig. 131 are used, the indication is not affected by the alternating-current fields. Hence the load current which is flowing in the cable will not interfere with the work of locating the fault. However, in cases of this kind it is necessary to clamp the generator instrument around all three conductors of a three-phase circuit to avoid errors due to the tracing current passing through the transformers or other apparatus which may be connected to the circuit.

The proper operation of the direct-current tracing-current method, therefore, depends upon conditions which will cause the tracing current to pass away from the cable into the ground at a point very near the fault. This will usually occur in systems where iron ducts are used. But in systems where tile duct is employed, cases are frequently encountered where a large portion of the tracing current passes into the lead sheath of the cable and continues along the sheath for a considerable distance in either direction or in both directions from the fault. In duct systems where cases of this kind are likely to occur it is necessary to use some method of detecting the sheath current and distinguishing it from the tracing current which is flowing through the conductor.

To distinguish between the tracing current and the sheath current, heavy copper clamps are placed around the conductor at points as widely separated as possible. In a manhole this will, of course, be at opposite duct edges. These clamps are connected together by a heavy copper shunt. Owing to the contact resistance of the copper clamp, it is usually impossible to reduce the sheath current to a negligible value if it is of considerable amount. However, a noticeable reduction is obtained, and by opening and closing a switch, which should be connected in the shunt, the comparative amount of sheath current can be determined.

If the indication of the millivoltmeter is reduced when the switch is closed, this indicates that the instrument is indicating sheath current only. Hence the location at which the reading is being taken is beyond the fault. If, when the switch is closed, the indication of the millivoltmeter is increased, this indicates that the instrument is reading both conductor current and sheath current, and that the location at which the reading is being taken is between the point of application and the fault.

As a final and accurate check on sheath current, the effect of this current can be entirely eliminated by cutting a ring out of the sheath at a point on each side of the place where the fault is suspected to be. In case the fault is not found at the suspected location, the sheath lead can usually be replaced without disturbing the insulation or making a new joint. If the fault is at the suspected location, no cable except that at the faulty section will be involved and it will not be necessary to replace the lead.

The direct-current method never fails to locate a fault surely and accurately, if a sufficient indication can be obtained to overcome the stray-current fluctuations and if the sheath current is properly taken into account. Furthermore, comparison in the field between the use of direct current, and alternating current has repeatedly shown that the former is, as to accuracy, far superior to the latter.

176. After The Approximate Location Of A Fault In A Cable Has Been Determined by any of the methods explained above, the cable is cut at the manhole nearest to the point where the fault is believed to be. But before the cable is cut at the man-

hole on the other side of the point where the fault is believed to be, tests should be made (at the end of the cut cable, Sec. 178) to determine whether the fault is actually between the station and the cut or whether the cut is between the station and the fault. The reason for making this final test is because sometimes, due to error, the fault is not where it appears to be. Hence unless this final test is made, a good section of cable may be cut, and pulled out. A great deal of time can be saved if such tests are made out on the line instead of repeating the tests which are outlined in Secs. 86 to 93. If the tests are made out on the line, the necessity for communicating with the station operator, after each time the cable is cut, is eliminated. How such tests can be made on the line is explained in following sections.

177. NOTE.—TO MAKE THE FINAL TESTS OUT ON THE LINE, the conductors of the faulty cable are connected (Fig. 132) through one or

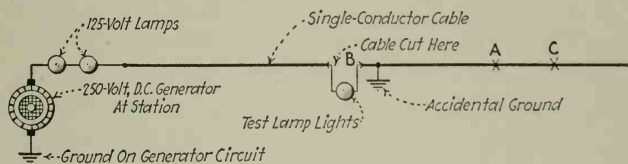


FIG. 132.—When a single-conductor cable is cut on the station side of a ground, the test lamp lights when its terminals are touched to the two bared ends of the conductor.

more lamp banks to a source of direct current at the station. One side of this direct-current circuit should be grounded. A 125- or 250-volt generator circuit is ordinarily used. In any event, the sum of the voltages of all the lamps in each bank at the station should be equal to the voltage of the circuit to ground to which the lamps are connected. That is (Fig. 132) if a 250-volt, two-wire generator, one side of which is grounded, is used, then each lamp bank should consist of two 125-volt lamps connected in series. This will, of course, result in the test lamp burning at reduced voltage, but it will prevent burning out the lamps of the bank.

178. In Locating A Ground In A Single-Conductor Cable Out On The Line, cut the cable as shown in Figs. 132 and 133. With the direct-current source connected to the faulty conductor through the lamp bank (Sec. 177), touch the test-lamp terminals to the bared ends of the conductor. If the lamp

lights (Fig. 132), the cut is between the station and the ground. If the lamp does not light (Fig. 133) the ground is between the station and the cut. Thus it can be determined whether to go toward or away from the station to make the second cut. If the above test indicates that the second cut is to be made at

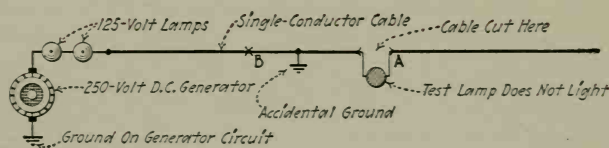


FIG. 133.—When a single-conductor cable is cut at a point so that the ground is between the station and the cut, the test lamp does not light when its terminals are touched to the bared ends of the conductor.

a point nearer to the station than the first cut, this same test is repeated at the second cut. However, if the second cut is made farther from the station than the first cut, repeat the test at the first cut after the second cut has been made. If the test lamp lights at the second test, the fault is between the two cuts. If at the second test, the lamp does not light, the ground is not between the two cuts. In this event, reconnect the cable at the first cut, and proceed as above outlined. See the following explanation.

179. EXPLANATION.—Assume that the first cut is made at *A* (Fig. 133). The test lamp when connected as shown remains dark, thus indicating that the next cut should be made nearer the station. Assume that the second cut is made at *B* (Fig. 133). Leave *A* open and test at *B*. If the lamp does not then light, a third cut must be made at a point nearer to the station than *B*. Continue making cuts until a point is found where the test lamp will light. When this is found, the ground will be between the point where the lamp lights and the cut next back on the line. If the first cut is made at *B* (Fig. 132), the test lamp will light, thus indicating that the next cut is to be made farther away from the station. After making this second cut, say at *A* (Fig. 132), the test is repeated, not at *A*, but at *B*. If the test at *B* lights the lamp, after the cut at *A* is made, the ground is between *A* and *B*. If the lamp, when applied at *B*, does not light after cut *A* is made, the ground is further from the station than *A*. In this event, jumper across the cut at *B*, make a third cut at *C*, and repeat the test at *B*.

180. Testing On The Line To Locate An Open-Circuit In A Single-Conductor Cable may be done as indicated in Fig. 134.

The generator circuit is connected through a lamp bank to the faulty conductor. If the test lamp is equipped with an "ice-pick" feeler (Fig. 21), the lead can be stripped off of the cable and the point of the pick pushed through the insulation to the conductor. In any event it is not necessary to cut the

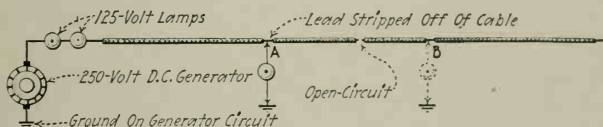


FIG. 134.—Testing on the line to locate an open-circuit in a single-conductor cable.

conductor in two until the faulty section has been localized. Touch one terminal of the lamp to the conductor and the other to the ground. If the lamp lights (A, Fig. 134), the open-circuit is farther from the station. If the lamp does not light (B, Fig. 134), the open-circuit is closer to the station.

181. NOTE.—TESTING ON THE LINE TO LOCATE AN OPEN-CIRCUIT IN A MULTI-CONDUCTOR CABLE may be done in essentially the same manner as that explained above for a single-conductor cable. The lamp bank at the station should be connected to all of the conductors in the cable. Then, in testing on the line, the lamp terminal should be touched to each conductor of the cable in turn. All of the conductors will light the test lamp if the test is made between the station and the open-circuit. If the test is made at a point on the line which is farther from the station than is the open-circuit, the conductor or conductors which have the open-circuit will not light the test lamp when they are touched with the test-lamp feeler.

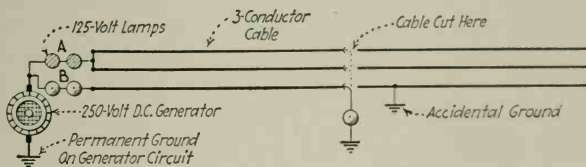


FIG. 135.—Testing on the line to locate a ground in a three-conductor cable.

182. Testing On The Line To Locate A Ground In A Conductor Of A Three-Conductor Cable may be done as indicated in Fig. 135. The two good conductors are looped together at the station and connected to a source of direct current through a lamp bank, A. The grounded conductor is connected to the

same source of direct current through a separate lamp bank, *B*. The cable is cut near to where the ground is believed to be and one terminal of the test lamp is grounded by fastening it to the lead sheath or sticking it into moist earth. The other terminal of the test lamp is touched to the station-side ends of each of the bared conductors in turn. If the lamp lights when each one of the three conductors is touched, the cut is between the ground and the station. If two of the conductors light the lamp and the third does not light it, the ground is between the station and the cut. The direction in which to proceed in making succeeding cuts, may be determined according to the same principles which are outlined in Secs. 178 and 180 for a single conductor.

183. Testing On The Line To Locate A Short-Circuit Between Two Conductors Of A Three-Conductor Cable can be accomplished as shown in Fig. 136. The good conductor is

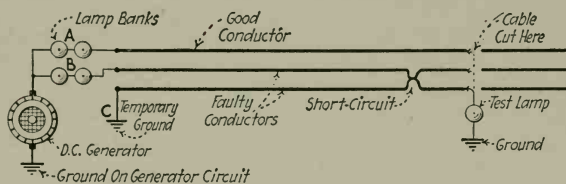


FIG. 136.—Testing on the line to locate a short-circuit in a three-conductor cable.

connected to a source of direct current through a lamp bank, *A*. One of the faulty conductors is connected to the same source of direct current through a separate lamp bank, *B*. The other faulty conductor is grounded at the station, as shown at *C*. After the cable has been cut, one terminal of the test lamp is grounded in the manhole. The other terminal is touched successively to the station-side end of each of the conductors. If the cut is made between the station and the short-circuit, the test lamp will light when two of the conductors are touched, and it will not light when the third conductor is touched. If the short-circuit is between the cut and the station, the test lamp will light only when one of the conductors is touched, and will not light when either of the other two are touched.

184. A Ground Or Short-Circuit On An Aerial Network Is Usually Located by sectionalizing portions of the network at the disconnect switches. That is, various portions of the line are isolated from the source of energy until one is isolated which removes the trouble. It is then known that this section contains the trouble and it is located by inspection. Even this is ordinarily unnecessary in a thickly populated district, because some resident will ordinarily report having seen a flash, smoke, or fire.

185. NOTE.—IN A TONE TEST ON AN AERIAL LINE, the tone-test instrument is connected to the line in the same manner as explained in Secs. 161 to 175. The exploring coil used is ordinarily either of the circular (Fig. 56) or triangular (Fig. 57) type and has an air core.

186. Faults In Aerial Lines May Be Located By Resistance Measurements in the same manner as explained hereinbefore for underground lines provided: (1) *The line is of sufficient length.* (2) *The fault is not in a network.* If the aerial line is too short for accurate resistance measurement, the fault can be readily located by a patrol inspection. Leaky insulators on high-tension lines can be located as explained in Div. 5. The tone-test method can sometimes be effectively applied in locating faults in a network. However, isolation is most frequently used. Ordinarily, there will be nothing gained by the tone test in locating a fault in a long aerial line that is not part of a network. The reason for this is that the fault is nearly always easily visible and a trip over the line without tone testing will reveal it quicker than with a tone test.

187. The Following Method Of Locating A Ground On Low-Voltage Secondary Distribution Lines, is illustrated in Fig. 137, is described in *Electrical World*, Oct. 26, 1920, by W. C. HESTON. The reactance coil (*R*, Fig. 137) consists of 600 turns of No. 15 wire wound on a laminated iron core having a closed magnetic circuit of about 6 sq. in. cross-section. Taps are brought out about every 100 turns so that the current may be varied. All permanent grounds are removed from the section under test. The reactance coil and ammeter are connected to the neutral and ground as indicated in the illustration. The reactance-coil tap is selected which will allow about 5 amp. to

flow through the ammeter. By holding an air-core type exploring coil (Sec. 53) with its plane parallel to the wire, a high-pitched hum can be heard. This high-pitched hum is

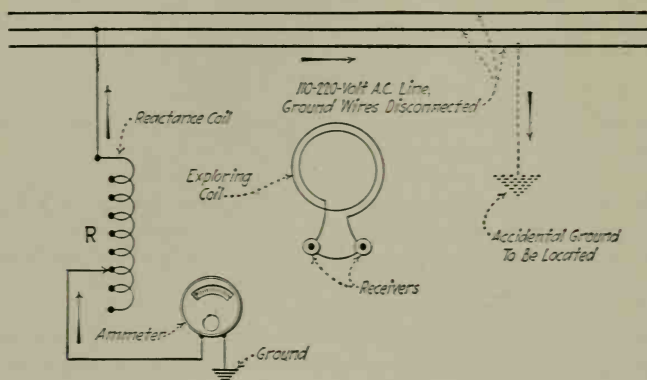


FIG. 137.—Connections for locating a ground on a 110-220-volt distribution system.

produced by the higher harmonics of the magnetizing current in the reactance coil. By carrying the coil along the line, the hum will cease when the ground is passed. If the hum ceases on passing a tap, follow the tap.

QUESTIONS ON DIVISION 2

1. What faults occur most frequently in electric circuits.
2. Define: *Ground*. *Short-circuit*. *Open-circuit*.
3. What is meant herein by *multiple transmission and distribution circuits*?
4. What are the four methods most frequently used in locating faults in transmission lines?
5. Why is a map essential in locating faults in an extensive wiring system?
6. Explain how an accidental ground manifests itself in a grounded circuit. In an ungrounded circuit.
7. Name several things which may cause a feeder circuit-breaker to open. How can the operator determine whether a circuit-breaker has opened due to a fault or to some other cause?
8. Explain how an open-circuit test can be made on high-voltage lines at a disconnect switch. Under what conditions may this test be misleading?

9. When a fault opens the circuit-breaker of a line, a part of which is overhead and a part underground, how is it determined in which part of the line the fault exists.

10. When a fault occurs on an underground system what should be done before making an attempt to locate it?

11. Explain how to make a test for a ground. Make a diagram of connections used.

12. If the test for ground shows "no ground," what may be the trouble?

13. Make a diagram of connections and explain the method employed in determining if the fault is a short-circuit.

14. Explain with a diagram how to make the test for open-circuit.

15. Why should direct current be used in determining the nature of a fault on a transmission line?

16. In locating a ground or a short-circuit by the resistance-measurement method, why must the resistance of the fault be low?

17. What is meant by "breaking down a fault?"

18. Name two methods of breaking down a fault. Make a diagram of and describe each method. Name the advantages and disadvantages of each method.

19. What are the two methods frequently employed in locating faults by resistance measurements?

20. Make a diagram of connections and derive the formula for the Murray-loop test.

21. Make a diagram of connections and derive the formula for the Varley-loop test.

22. Which of the above two tests, the Varley- or the Murray-loop, is the better adapted for the measurements in locating faults in low resistance conductors such as power cables?

23. Why must the temperature of a conductor be considered in locating faults by resistance measurements?

24. When the loop, which is being used to locate a fault, consists of conductors of different resistances per unit length what must be done?

25. Explain how to reduce the resistance of one conductor to the equivalent length of another conductor.

26. Explain why a loop must be made in locating a ground by the resistance-measurement method.

27. What is the most practical method of locating grounds by resistance measurement?

28. Explain how to locate a ground with the home-made fault locator.

29. What is the accuracy which must be maintained in locating faults in an underground cable system?

30. Explain how the home-made fault locator operates in accordance with the principle of the Wheatstone bridge.

31. Make a diagram of connections and explain the method of locating a fault with the L. & N. Power Bridge.

32. Make a diagram of connections and explain the method of locating a fault with the Westinghouse Portable Fault Localizer.

33. Make a diagram of connections and derive the formula for locating a ground by the two-ammeter method.

34. Explain with a diagram how to locate a short-circuit in a multi-conductor cable by the resistance-measurement method.

35. What are the two principal sources of error in locating faults by resistance measurements?

36. How may such errors be partially compensated?

37. How does an open-circuit on a transmission line usually manifest itself?

38. What method is ordinarily employed in locating an open-circuit?

39. Make a diagram of the Wheatstone-bridge circuit for determining the electrostatic capacity of a condenser, and derive the formula which applies.

40. In determining the capacity of a condenser, what must be done after each time the condensers are charged? Why?

41. What are the three principal methods of locating an open-circuit in a multi-conductor underground cable?

42. Make a diagram of connections and derive the formula for locating an open-circuit without looping the conductors by means of the home-made fault locator.

43. Make a diagram of connections and derive the formula for locating an open-circuit with one good conductor looped to the faulty conductor when using the home-made fault locator.

44. Make a diagram of connections and derive the formula for using the home-made fault locator to locate an open-circuit when the faulty conductor is looped to the good conductor at both ends of the line.

45. Make a diagram of connections and derive the formula for using the L. & N. Power Bridge to locate an open-circuit when: (a) The line is not looped. (b) When the faulty conductor is looped to a good conductor at the far end of the line. (c) When the faulty conductor is looped to a good conductor at both ends of the line.

46. What are the advantages and disadvantages of the three methods of locating open-circuits in underground cables?

47. Explain the principle involved in locating faults by the tone-test method.

48. What faults may be located by a tone test?

49. Explain with a diagram how to locate a fault with the Telefault?

50. Make a diagram of connections and explain how to locate a fault with the Queen Wireless Test Set.

51. Name the faults which may be located with the Lundin Fault Locator.

52. In locating a fault by the tone test, why should the exploring coil be applied to the cable near the instrument before going out on the line?

53. What is ordinarily the quickest and most reliable procedure in locating a fault in an underground cable?

54. Explain with a diagram the "halving the distance" method of locating a fault. Under what circumstances in such a method employed?

55. What are the two principal effects which cause errors in locating a fault by a tone test?

56. What is the *fault current*? The *sheath current*.

57. Explain two conditions whereby the sheath current may be productive of misleading when locating a fault by the tone-test method.

58. How can the effect of sheath current of a multi-conductor cable sometimes be detected?

59. Explain a method whereby the sheath current may be utilized to aid in the location of a ground in a single-conductor cable.

60. What is the effect of the electrostatic capacity when one is endeavoring to locate a fault in an underground cable by a tone test?

61. After the approximate location of a fault in an underground cable has been determined, explain how to definitely locate the following faults by testing on the line for a single-conductor and for a multiple-conductor cable: (a) Ground. (b) Short-circuit. (c) Open-circuit.

62. How may faults in aerial lines be located?

63. What is the usual procedure in locating a fault in an aerial network?

64. Explain with a diagram a method of locating grounds on low-voltage secondary distribution lines.

PROBLEMS ON DIVISION 2

1. In locating a ground with the home-made fault locator on a cable which was 29,300 ft. long, the galvanometer balanced at a reading of 42.5. What was the distance to the fault?

2. The "L. & N. Power Bridge" when used to locate a short-circuit between two conductors of a three-conductor cable which is 21,200 ft. long balances at a reading of 259. How far is the fault from the bridge?

3. In testing to locate a ground with the Westinghouse Portable Fault Localizer, the balance was obtained with a scale reading of 86. The cable was 6,780 ft. long. How far was it to the fault?

4. In using the two-ammeter method of locating a ground on a cable 9,400 ft. long connected as shown in Fig. 100, ammeter *B* read 2.62 amps. and ammeter *A* read 4.12 amps. How far was it to the fault?

5. An open-circuit was being located with the home-made fault locator without looping the conductors. The cable was 18,200 ft. long. The scale reading was 46.4 when the galvanometer showed no "kick." How far was the fault from the instrument?

6. In locating an open-circuit with the home-made fault locator, the faulty conductor is looped to one good conductor at the far end of the line. The balance is obtained at a reading of 66. The length of the cable was 34,600 ft. How far was it to the open-circuit?

7. An open-circuit in one conductor of a three-conductor cable, which was 24,600 ft. long, was being located with the home-made fault locator with a loop at both ends of the line (Sec. 148). The balance was obtained at a reading of 72 with the red lead connected to the loop. How far was it to the fault?

DIVISION 3

LOCATING FAULTS IN INTERIOR-WIRING CIRCUITS

188. A Fault On An Interior-Wiring Circuit Usually Disrupts The Operation Of The Circuit.—The fault may be caused by a defective current-consuming device connected to the circuit, or it may be due to a failure of the circuit-wiring proper. The different kinds of faults and methods of localizing them will be described in the following sections. Only those faults which occur on the circuit proper will be considered in this division.

189. The Faults Which Occur On An Interior-Wiring Circuit Are Usually Caused By One, Or A Combination Of The Following Troubles: (1) *Open-circuit*. (2) *Short-circuit*. (3) *Accidental ground*. Method of localizing these troubles on interior-wiring circuits are described, in the order named, in following sections.

190. Faults On Interior Circuits Can Ordinarily be Localized To Within A Comparatively Small Region by noting what apparatus does not operate. That is, if only one device is not operating and this device is connected to a branch circuit, which also serves several other devices which are operating, it is known that the trouble is in the non-operating device or in the leads which serve it. If all of the apparatus on one branch circuit fails to function, and the apparatus on the other branch circuits which are served by the same feeder are functioning, then the fault is somewhere on the branch circuit which is in trouble. Therefore, for efficient and prompt fault location, it is necessary to have a thorough knowledge of the wiring layout. Such thorough knowledge of the wiring layout can best be obtained from diagrams, which show the location of all electrical apparatus, the wiring which serves the apparatus, and the fuses or other protective devices which are contained in the circuits.

191. NOTE.—A CIRCUIT DIRECTORY SHOULD BE CONTAINED IN EACH PANEL BOX OR DISTRIBUTION CABINET.—This directory should be typed on a sheet of paper and the sheet secured (in a frame and under glass to keep it clean) to the inside of the door. The circuits in each panel box or distribution cabinet should be stamped with a number. The directory should show, by branch-circuit number, what rooms or devices are served by each circuit. Then, if all of the lights are out in a given room, it is a simple matter to go to the panel box and examine the fuses for the circuit which feeds that room. This obviates the testing of each fuse on the panel.

192. An Open-Circuit (Sec. 75) frequently occurs in combination with a short-circuit or a ground. That is, if a circuit becomes grounded or short-circuited, the heavy current which then flows usually ruptures a fuse or operates whatever protective device is next back on the line, thereby opening the circuit. However, (Sec. 212) a blown fuse does not necessarily indicate that one of the other faults also exists. Other causes of open-circuits are: (1) *Wire severed by a mechanical or other injury.* (2) *High-resistance splice.* (3) *Loose contact.* (4) *Burned in two by heavy current or arc* (Sec. 193).

193. An Open-Circuit May Be Caused By An Accidental Ground.—Such an open-circuit occurs most frequently where the insulation on the conductor in a conduit system has been injured and does not manifest itself until some time later. Water may accumulate in the conduit and the weak point in the insulation is broken down, permitting the conductor to come in contact with the conduit. If this conductor is the ungrounded conductor of a permanently grounded system, an arc is formed at the point where the conduit and conductor come in contact. If the fuse or protective device which protects the circuit does not function quickly, the arc formed may burn off the conductor at that point causing an open-circuit. However, the ground usually causes the protective device to function before the conductor is burned open, and frequently the arc welds the conductor to the conduit.

194. NOTE.—A FUSE MAY BLOW OUT ON A CIRCUIT WHERE NO FAULT EXISTS.—An additional electrical appliance may have been connected, such as an electric toaster, a washing machine, or a heater, which requires probably 6 amp. to operate. This additional load on the circuit may exceed the rating of the fuses and thereby cause the fuses to blow.

In this event, it is necessary to increase the ampere capacity of the fuses on the circuit to which the additional appliance is connected. It may also be necessary to increase the ampere rating of the service-entrance fuses, especially where only two or three branch circuits are fed from the service.

195. NOTE.—THE 1923 NATIONAL ELECTRIC CODE LIMITS THE CAPACITY OF A BRANCH LIGHTING CIRCUIT TO 15 AMP.—When the addition of an electrical appliance increases the current above the value which will satisfactorily flow through 15-amp. fuses, an additional circuit should be installed so that the 15-amp. fuses will properly protect the circuit. For example, should an existing circuit be loaded so that the current consumption is 12 amp., and an appliance requiring 6 amp. is added, it will be necessary to run an additional circuit, and so divide the load to be within the requirements of the CODE.

196. An Open In A Two-Wire Lighting Circuit (Fig. 138) may cause all or a part of the lights on the circuit to be extinguished. If the open occurs between the feeder and the first lamps on the circuit, it is obvious that all the lamps on that circuit will fail to burn. However should the open occur at a point as indicated by *O* (Fig. 138) the lamps beyond that point will be extinguished, while those lamps ahead of the open will continue to burn. Thus, the way in which an open-circuit manifests itself may serve to locate it.

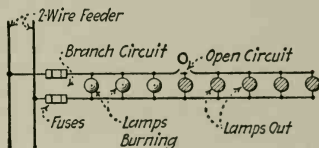


FIG. 138.—Diagram showing the effects of an open in a 2-wire lighting circuit. An open at *O* causes all the lamps beyond the open to be extinguished.

197. An Open In The Neutral Wire Of A Three-Wire Lighting Circuit May Cause An Excessive Voltage To Be Impressed On Some Of The Lamps (Fig. 139).—The system shown in Fig. 139 is, as a whole, balanced, and should the open occur at *X*, no serious trouble would occur, so long as the system remains balanced. But should the open occur at *O*, as shown, the portion of the circuit beyond this point is unbalanced and the lamps on circuits *B* and *B*₁ would burn at a decreased voltage, whereas those on circuits *A* and *A*₁ would burn at an increased voltage. However, the lamps on circuits *C*, *C*₁, *D*, and *D*₁ would, since they are balanced, continue to operate at normal voltage, which is maintained through the neutral.

198. An Open In A Polyphase Motor Circuit May Cause A Fuse To Blow (Fig. 140 and 141).—If an open occurs in a two-phase, 4-wire motor circuit, as shown in Fig. 140, the motor

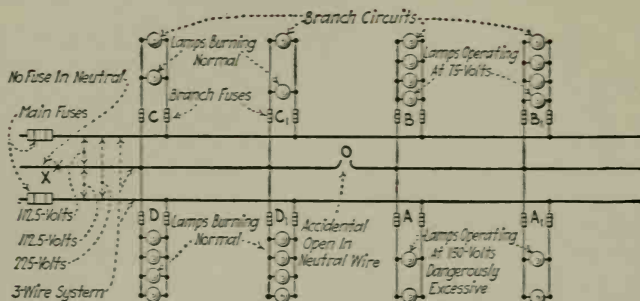


FIG. 139.—Diagram showing the effect of an accidental open in the neutral of a three-wire lighting circuit. If the system has a potential of 225 volts between outer wires and 112.5 volts from either outer wire to neutral, an accidental open in the neutral as shown at *O* will cause a voltage at 75 volts to be impressed on lamps at *B* and *B*₁, and 150 volts on lamps at *A* and *A*₁, assuming that all the lamps are the same wattage. Such excessive voltage at *A* and *A*₁, is, in the majority of cases sufficient to cause the lamps to burn out.

will run single-phase and draw an excessive current from the circuit. This excessive current frequently causes the fuses or

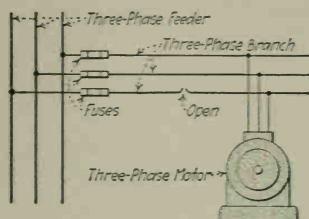


FIG. 140.

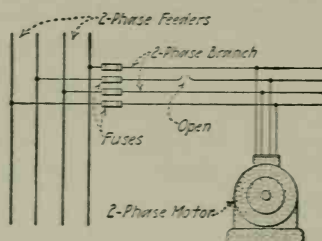


FIG. 141.

FIG. 140.—Diagram of a three-phase motor circuit with an open in one of the conductors.

FIG. 141.—Diagram of a two-phase system with an open in a motor branch circuit. If the motor is fully loaded and the open occurs while the motor is operating, the current in the other phase will be approximately doubled. Should the overload protective device in the circuit fail to function, the windings of the motor will become damaged due to the excessive heat produced by the increased current flowing through them.

other protective devices to function, thereby preventing the motor windings from being damaged. Frequently, this excessive current due to "single-phasing," is not sufficient to

cause the protective devices to function but is sufficient to roast (overheat) the windings. Similar effects will result on three-phase motor circuits (Fig. 141) when an accidental open occurs.

199. NOTE.—AN OPEN IN A POLYPHASE MOTOR CIRCUIT WILL PREVENT THE MOTORS ON THE CIRCUIT FROM STARTING.—This is due to the fact that the open in the circuit permits but a single-phase current to excite the motor. The characteristics of a polyphase motor are such that it will not start on a single-phase current. However, if the motor is running and the open occurs, the motor will continue to run, provided the load is not excessive. Should the load be such that the motor will not continue to run on single-phase current, it will slow down and stop, blow out the fuses or cause other protective devices to function, or, if not disconnected from the line, burn up the windings.

200. A Blown Primary Fuse On A Three-Phase Power Circuit Often Misleads When Testing For Trouble On The Secondary Circuit Supplied Through The Primary Fuse.—

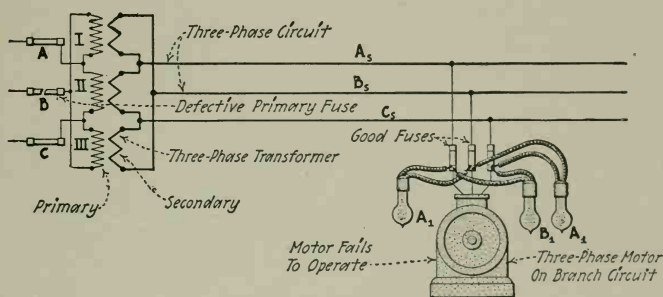


FIG. 142.—Diagram showing the effects of a defective fuse in the primary circuit of a three-phase circuit. The lamp burns at a decreased brilliancy in positions A₁A₁ and at full brilliancy in position B₁.

Figure 142 illustrates such a condition. The primary fuse at B is blown out; transformers I, II and III still have a potential impressed upon them. However, the voltage on I and III is approximately one-half of normal, since transformers I and III are now in series across phase AC. Transformer II has normal voltage impressed on it. The secondary voltages produced by the transformers will have the same relative values as those impressed on the primary side of the transformers. The three voltages thus produced between the three wires of the secondary circuit will all be in phase. Also the voltage

between B_s and A_s and between B_s and C_s , will be only one-half that between A_s and C_s . This form of trouble can usually be detected by the difference in brilliancy of the test lamp when it is connected in the different positions. When the test lamp is connected in position A_1 and A_2 it will burn at a reduced brilliancy; and when connected as shown at B_1 , it will burn at full brilliancy.

201. NOTE.—A FAULTY FUSE IN THE SECONDARY OF A THREE-PHASE POWER CIRCUIT MAY CAUSE MISLEADING INDICATIONS WHEN TESTING FOR FAULTS (Fig. 143).—This is true only when the fuse on the circuit

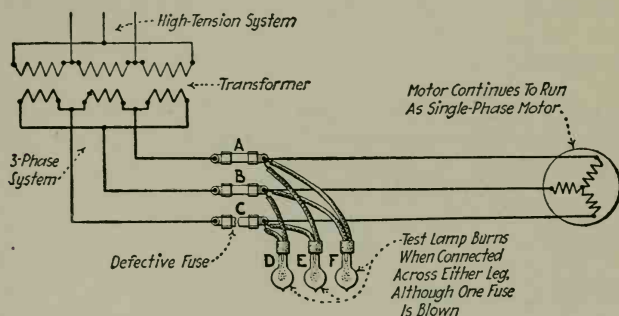


FIG. 143.—Diagram showing how a defective fuse may cause a misleading indication on the test lamp. This is due to the phase of the motor winding which is connected to the faulty circuit, having a potential induced in it by the other phase. If the defect in the fuse occurred while the motor was running, the motor will continue to run on single-phase current but the horse-power output of the motor will be greatly reduced.

blows while the motor on the circuit is running, the load on the motor being such that the motor will continue to operate as a single-phase motor. If the fuse at C (Fig. 143) is blown, however, the motor continues to operate, supplied by a single-phase current from conductor AB. (The motor will not start with a fuse blown.) When testing such a circuit for faults with a test lamp, as shown at D, E and F, the lamp will burn with approximately the same brilliancy across each of the phases. This is because a voltage will be induced by the motor between wires B and C which will be approximately equal to the normal line voltage. To avoid being misled by these indications, the fuses should always be tested with the motor disconnected from the circuit.

202. To Locate A Defective Fuse With A Test Lamp (Figs. 144 and 145) proceed as follows: If the faulty circuit terminates in a panel box which serves many other circuits, it

is first necessary to determine through which pair of fuses the faulty circuit is fed. This is done (Figs. 144-I and 145-I) by touching the feelers of the test lamp to the load-side terminals

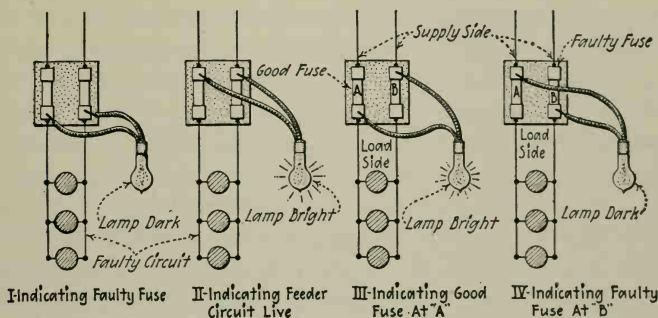


FIG. 144.—Diagram showing the progressive steps in testing for a blown fuse, with a test lamp.

of each pair of circuit fuses in succession until one pair of circuit fuses (AB, Fig. 145-I) is touched which does not light the test lamp. Then it is known that one of the fuses, either

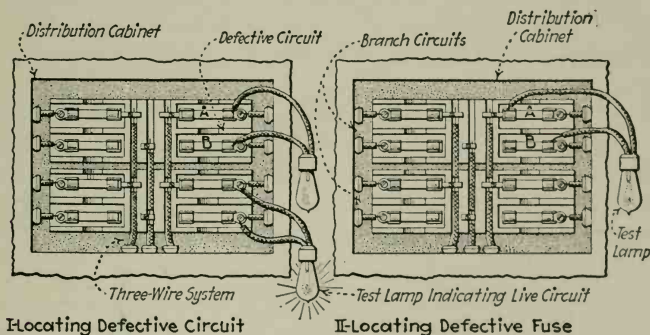


FIG. 145.—Diagram illustrating the method of locating a defective fuse with a test lamp.

A or B, is blown. Which of the fuses, A or B, is blown, may be determined by touching the test-lamp feelers to the supply side of one fuse and to the load side of the other fuse (Fig. 144-III and -IV, and Fig. 145-II). If the test lamp lights when this is done, it indicates that the fuse terminal is touched on the load side (A, Fig. 144-III) is good. If the test lamp

does not light, it indicates that the fuse whose terminal is touched on the load side (*B*, Fig. 144-IV) is burned out. Always make the above tests to determine if both fuses are good or if both are defective. If both fuses test defective, that is, if the test lamp remains dark when tested as shown in Fig. 144-III and -IV, touch the test lamp to the supply side of both fuses as shown in Fig. 144-II. If the lamp then lights, both fuses are defective. If the lamp does not light, the open-circuit is further back on the line. After having located the defective fuse, the next step is to determine what caused it to blow. How this may be done is explained below.

203. The Method Of Locating A Blown Fuse On A Motor Circuit is, for a two-wire motor, essentially the same as that outlined in Sec. 202 for a lighting circuit. If the motor is a

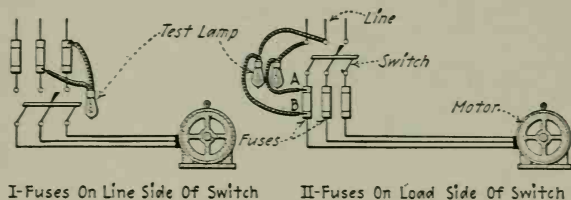


FIG. 146.—Method of locating a defective fuse in a polyphase motor circuit.

four- or a three-wire machine, with the fuses on the line side of the switch (Fig. 146-I), this method can also be used. But if the fuses of a four- or a three-wire motor are on the load side of the switch (Fig. 146-II), use two test lamps with two of their leads connected to the line-side terminals of the switch. Then simultaneously touch the other two feelers (*A* and *B*) of the test lamps to the ends of each fuse in succession. If the test lamps light, the fuse being tested is good. If the test lamps do not light, it indicates that the fuse has burned out. To be certain that a voltage is being impressed upon the lamps, touch *A* and *B* together and see whether or not they light.

204. To Locate An Open-Circuit In A Lighting Circuit, proceed as follows: When the open-circuit occurs on an open wiring system an inspection of the circuit will usually reveal the location of the fault. If the open occurs in such a place on the circuit that only a part of the lamps burn, the open will

be found between the lamps which do not burn and those which operate normally, as shown in Fig. 138. When none of the lamps on a circuit burn, and the fuses have been tested (Sec. 202) and found to be in good condition, the open has occurred between the branch-circuit cut-out and the first lamp connected to the circuit as illustrated in Fig. 147. When an open occurs in a conduit-wiring system, it is necessary to pull out the conductors between the two outlet boxes between which the open occurs, as shown in Fig. 148.

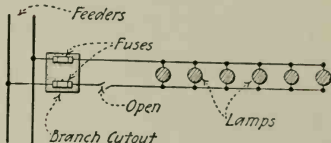


FIG. 147.—Diagram showing an "open" in a lighting circuit so located in the circuit that all the lamps on the circuit fail to burn.

When an open occurs in a concealed knob-and-tube wiring installation, the localizing and repair of a fault is more difficult. If it is impossible to fish a new conductor to replace the faulty conductor, it becomes necessary to remove flooring or plaster to permit the replacement of the conductor.

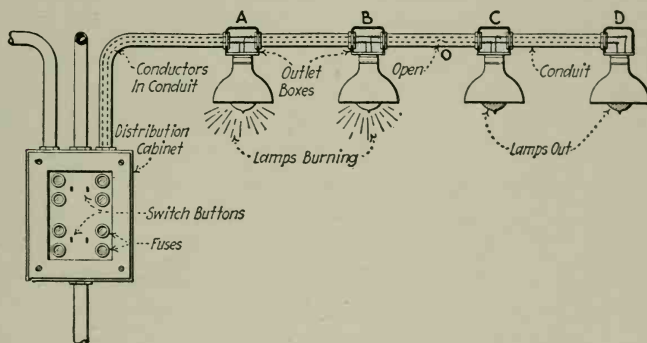


FIG. 148.—Diagram showing an open in a conduit system. The open exists between outlet box B and C, as shown at O. To repair the fault, the conductors must be pulled out of the conduit between outlet boxes B and C and the faulty conductor replaced with a new conductor.

205. NOTE.—AN OPEN-CIRCUIT IN A CONDUIT RUN CAN BE LOCATED WITH A MAGNETO as indicated in Fig. 149. The conduit boxes at each end of the run are opened and the conductors in the conduit are disconnected from the source of voltage at the first switch or fuses back on the line. Ground all of the conductors in the conduit to the box at E. Connect one terminal of the magneto to the box A. Then successively connect the other terminal of the magneto to each conductor in A and

turn the magneto crank. The conductor to which the magneto is connected when it will not ring is the one which has the open-circuit. Then "halve the distance" (Sec. 167) and make a similar test at *C*. Now repeat the same test at *D*. When the test is made at *D* the magneto will ring on all of the conductors. This indicates that the open-circuit has

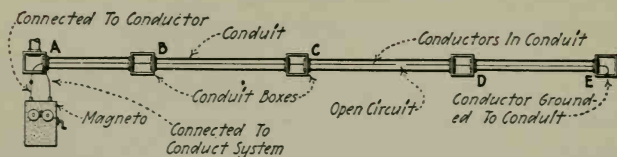


FIG. 149.—Locating, with a magneto, an open-circuit in a conductor installed in conduit.

been passed. Thus, it is determined that the open is between *C* and *D*. In this way an open-circuit in a conduit run can be located to within the distance between two outlet boxes. It is of course obvious that any of the bell-and-battery test sets described in Div. 1 could be used instead of the magneto.

206. An Open-Circuit, Or A Break, In An Extension Cord Can Be Quickly Located with the device (Fig. 150) which is described below. Remove the cap from a $\frac{3}{8}$ -in. brass lamp

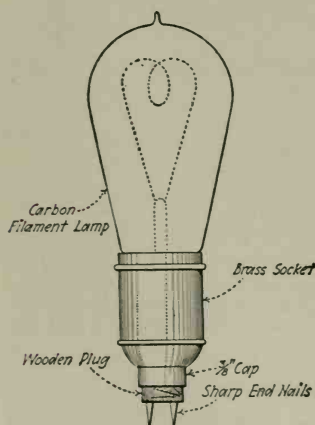


FIG. 150—Device for locating an open-circuit in an extension cord.

socket. Screw a wooden plug into the cap. Then drive two small finishing nails through this plug. Solder a short piece of fixture wire to each nail and connect the fixture wires to the socket-terminal screws. Replace the cap on the socket. File the outside ends of the nails to a sharp pin point. Screw a low-wattage, say a 15-watt, lamp into the socket. Connect the faulty extension cord to a live receptacle. Now by pressing the sharp points of the nails through the insulation into the stranded wire—one nail into each wire—the lamp will light on the live side of the break. After the break has been passed the lamp will not light.

207. For Locating Open-Circuits In A Wiring System Before The Service Connection Has Been Made, the devices shown in Figs. 151 and 152 may be used as follows: With all fuses in place, connect two dry cells to the busbars of the panel board as shown in Fig. 153. Then, with all local switches closed, go over the installation and push one of the fixture-testing devices of Figs. 29 or 30 into each socket as shown in Fig. 152. If the buzzer sounds or the lamp lights, the circuit is complete. However, if upon pushing the device into a socket the buzzer does not sound (or the lamp does not light), there is an open-circuit somewhere on that branch. The construction of the fixture-testing device as shown in Figs. 151 and 152 is self-explanatory. Sometimes a wireman will forget to connect a tap circuit to the branch. Unless some test, similar to that described above, is made, a return trip will have to be made to correct the fault after the service is connected.

208. The Principal Causes For Blown Fuses On Lighting Circuits are: (1) *Fuse of insufficient capacity to carry the current of the normal load, or of a momentary overload.* (2) *Short-circuit or ground.* Which of the above conditions has caused the fuse to blow may be determined as explained in the following section.

209. To Determine What Has Caused A Lighting-Circuit Fuse To Blow, turn off all except one or two of the lamps on the circuit. Remove the defective fuse and connect the test lamp across the fuse terminals (Fig. 154-I), or screw a lamp into the fuse receptacle (Fig. 154-II). If this lamp burns at normal brilliancy and the lamps which are connected on the circuit do not burn, there is either a short-circuit or a ground somewhere on the circuit. If the test lamp and the lamps which are connected on the circuit burn at reduced brilliancy,

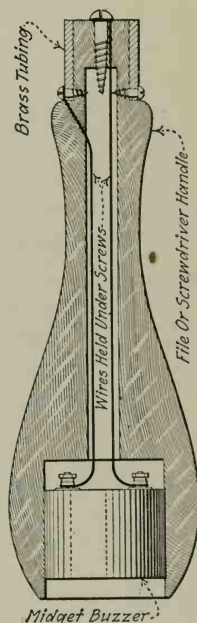


FIG. 151.—Device for testing for open-circuits at lamp sockets before service connection has been made.

there is no short-circuit or ground on the circuit. Then, a good fuse may be inserted. The reason why all except two or

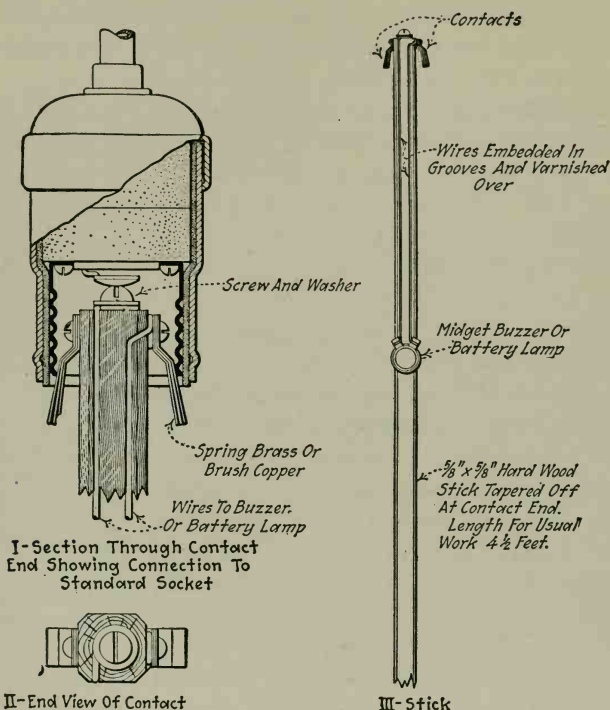


FIG. 152.—Socket testing device mounted on a wood stick for convenience in testing ceiling outlets.

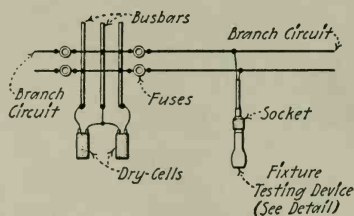


FIG. 153.—Method of using the fixture-testing device to locate open-circuits before the service connection has been made.

three lamps on the circuit should be turned off before making this test is: If there should be several high-wattage lamps on the circuit which are turned on, their combined resistance in

parallel may be so low that the brilliancy of the test lamp may not be sufficiently reduced to be readily noticeable. In this event, one may spend a lot of time hunting for a short-circuit or ground which does not exist.

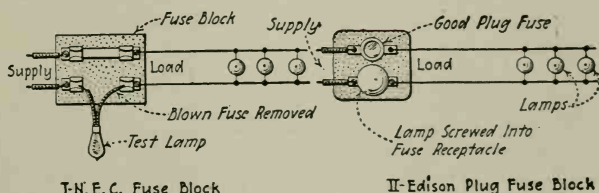


FIG. 154.—Illustrating method of determining what caused the fuse in a lighting circuit to blow.

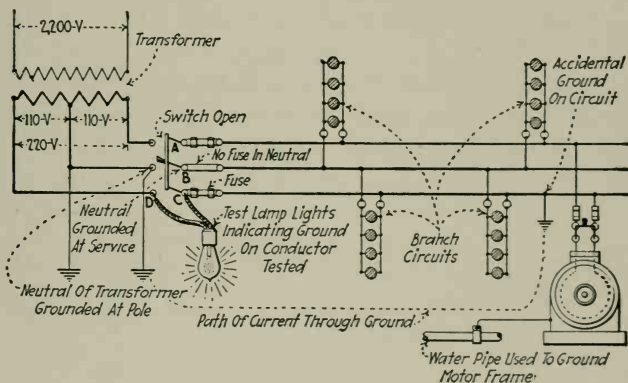


FIG. 155.—Illustrating the principle of testing a circuit to determine whether a ground exists on the circuit. The switch in the main is opened. The test lamp is connected, by means of one of its feelers, to the ungrounded conductor of the service and the other test lead is connected consecutively to each of the conductors *A B* and *C* of the circuit. When the lamp lights on one of the circuits as at *C* it is an indication that the conductor which is being tested is grounded.

210. NOTE.—IF THE ABOVE TEST SHOWS THAT THE TROUBLE ON A LIGHTING CIRCUIT IS BEING CAUSED BY A SHORT OR BY A GROUND, it may be determined if it is a ground by making the following test: Open the first switch (Fig. 155) back on the line on the load side of the blown fuse, or disconnect the line which is in trouble by removing the fuses (Fig. 156) through which the line is supplied. Then touch one feeler of the test lamp to an ungrounded wire on the supply side of the switch *D* (Fig. 155) or on the supply side of the fuse (Fig. 156), and touch

the other feeler successively to the terminals *A*, *B* and *C* (Fig. 155), on the load side of the switch, or *A* and *B* (Fig. 156) on the load side of the fuses. If the lamp lights on any terminal *A*, *B* or *C*, the trouble is caused by a ground, and the ground is somewhere on the conductor, the terminal of which causes the lamp to light. If the lamp does not light, the fault is probably a short-circuit. The test to determine whether a short-circuit exists is explained in the following section.

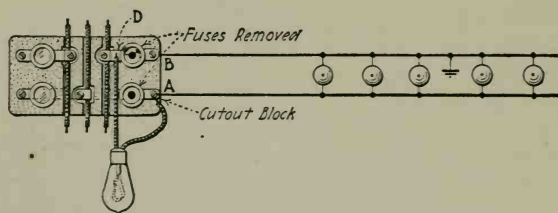


FIG. 156.—Test to determine whether or not an accidental ground exists on a two-wire circuit which is fed from a circuit which has one conductor permanently grounded.

211. To Determine If There Is A Short-Circuit On A Branch Lighting Circuit, first make the test for grounds as explained above. If the circuit is free from grounds proceed as follows:

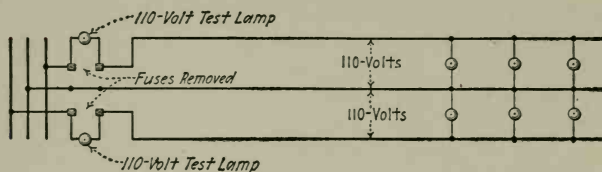


FIG. 157.—Test for short-circuit to be made on a three-wire branch circuit after it has tested free of grounds. If either of the test lamps burns at normal brilliancy there is a short-circuit on that circuit.

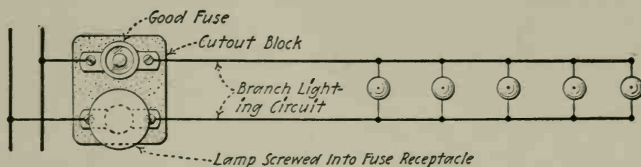


FIG. 158.—Test for short-circuit to be made on a two-wire branch lighting circuit after the circuit has been tested for grounds. If the lamp burns at normal brilliancy, there is a "short" somewhere on the circuit.

For a three-wire circuit, remove both fuses (Fig. 157). For a two-wire circuit remove one fuse (Fig. 158). Then connect a test lamp (Figs. 157 and 158), which is of the same voltage

rating as the circuit voltage, across the fuse terminals where the fuses have been removed. If the test lamp burns at normal brilliancy there is a short on that circuit.

212. A Fuse On A Motor Circuit Frequently Ruptures Due To A Momentary Overload, consequently, when such trouble occurs, the blown fuse is located (Sec. 202), and a good fuse immediately inserted. Of course, if there is a short or a ground on the circuit, a fuse will again be blown as soon as the motor-controlling switch or starter is closed. Whether or not there is a ground on the circuit can be determined in the same manner as that for a lighting circuit (Sec. 210). If this test (Sec. 210) shows a ground, disconnect the leads at the motor terminals and repeat the test. If the test now shows that the ground still exists, the fault is in the wiring between the fuses and the motor terminals. If, after the leads have been disconnected the test shows no grounds, the fault is in the motor winding. If the above test which is made before disconnecting the motor leads does not indicate a ground, disconnect the leads and test for a short-circuit as explained in Sec. 211. If this test shows no short-circuit the trouble is in the motor.

213. NOTE.—MOTOR FUSES ARE FREQUENTLY RUPTURED BY A MOMENTARY OVERLOAD.—This is the reason why, in the long run, it is ordinarily better to replace a blown motor fuse immediately without testing for trouble. If the test were made every time a motor fuse was blown a great deal of time would be spent hunting for a fault which did not exist. Consequently when a motor fuse blows, a good fuse is immediately put in its place. Then, if it blows the instant an attempt is made to start the motor, search for the fault.

214. In Determining The Exact Point Where A Ground Or Short-Circuit Is Located the kind of apparatus which is connected to the circuit should be considered. About 90 per cent of the grounds and short-circuits on an interior-wiring system occur in the flexible cord or fixture wire which feeds lamps or devices, or in motors. Consequently, when attempting to locate these faults, such apparatus should be regarded with suspicion. In the following sections, several methods are explained for locating a ground or a short-circuit on lighting and motor circuits.

215. Short-Circuits And Grounds In Motor Circuits May Be Located with test lamps as explained in Sec. 210. However, if the voltage of the circuit is so high that test lamps are inconvenient, a voltmeter may be used to locate the blown fuse. When this is done the voltmeter is used in precisely the same manner as is the test lamp, the voltage reading of the voltmeter being noted instead of the lighting of the lamp. Then, after the blown fuse has thus been located, a magneto may be used in locating the ground or short-circuits as follows:

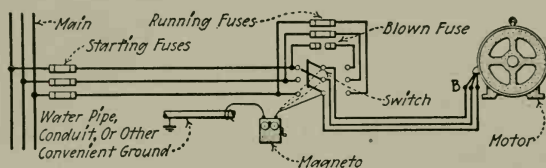


FIG. 159.—Locating a ground in a motor circuit with a magneto.

216. EXPLANATION.—Open the motor disconnect switch or starting switch (Fig. 159). Connect one terminal of the magneto to some

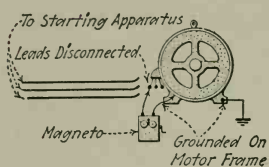


FIG. 160.—“Ringing” out a motor for a ground.

grounded object, such as the conduit, a water pipe, or the like. Then touch the wire from the other magneto terminal successively to each of the other terminals of the switch. If, while this wire is touching any terminal, the magneto will ring, then the circuit is grounded. If this test indicates a ground, disconnect the conductors from the motor at B (Fig. 159), and repeat the test. If the second test indicates a ground, the fault is on the conductor, which gives the ring, between the switch and B. If this test does not give a ring, make the same test on the leads which come out of the motor (Fig.

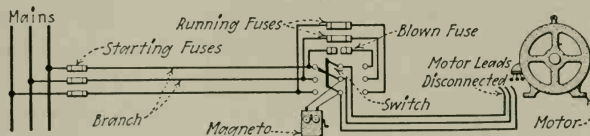


FIG. 161.—Locating, with a magneto, a short-circuit in a motor circuit.

160). If the test on the motor (Fig. 160) indicates a ground, the motor must be repaired. If this test in Fig. 160 does not indicate a ground, test the wiring between the switch and the motor for short-circuits, as

indicated in Fig. 161. With the motor leads disconnected at the motor (Fig. 161), connect the magneto terminals across each pair of switch terminals in succession. If the magneto will ring when connected across any pair, the conductors are short-circuited.

217. NOTE.—ANY OF THE TESTING SETS DESCRIBED IN DIV. 1 MAY BE USED INSTEAD OF A MAGNETO for locating trouble in a motor circuit. That is, any of the devices which indicate a closed circuit, such as the battery and bell, the battery and lamp, or the battery and telephone receiver, could be used for testing the motor circuit.

218. After Having Located The Blown Fuse On A Branch Lighting Circuit And Determined Whether Or Not The Fault Is A Ground Or A Short-Circuit (Secs. 202, 210, and 211),

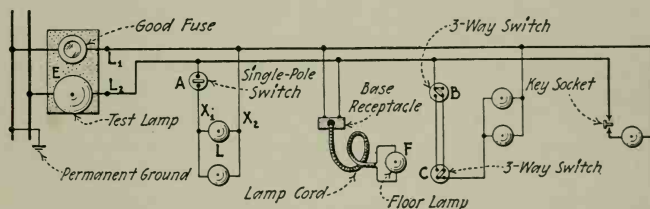


FIG. 162.—Locating a short-circuit or a ground on a branch lighting circuit.

remove the defective fuse and screw a lamp into that fuse receptacle, as indicated in Fig. 162. Then operate successively each switch (A, B and C) on that branch circuit and unplug all flexible-cord connections. If the ground or short-circuit is on any of the fixture wiring which is controlled by a switch, the test lamp will burn at reduced brilliancy, or go out entirely (Sec. 219), as soon as that switch is operated. The same thing will occur when a flexible cord is unplugged if the trouble is in that cord. If there is a three-way switch circuit on the branch which has the trouble, each of the three-way switches (B and C) should be operated. It is not sufficient to operate only one of the three-way switches. By this method, most of the short-circuits or grounds which occur on lighting circuits can be located in a minimum time. See the following example.

219. EXAMPLE.—Assume that a short-circuit or a ground has developed in the fixture wiring at X_1X_2 in Fig. 162. The blown fuse is located, as explained in Sec. 202, removed, and a lamp, E, screwed into the fuse receptacle. This lamp will now burn at normal brilliancy. When switch A is opened, the test lamp will either go out—if no other lamps on

this circuit are turned on—or it will burn at reduced brilliancy. If any other visible lamp, such as the floor lamp, *F*, is on the same branch circuit with lamps *L*, it also will not burn while switch *A* is closed; hence it may be employed as a temporary test lamp. But as soon as switch *A* is opened, the floor lamp will light up at reduced brilliancy. Thus, by watching the other lamps on the circuit, it can be determined, when the switches are operated, which switch is controlling the faulty wires. If this procedure is followed, it may not be necessary to make a trip to the panel box, to observe the test lamp, each time a switch is manipulated.

220. NOTE.—THE TROUBLE CAUSED BY A GROUND ON A TWO-WIRE BRANCH CIRCUIT WHICH HAS ONE SIDE PERMANENTLY GROUNDED may be temporarily corrected by reversing the connections at the fuse block. Thus, if it is determined, as explained in Sec. 210, that the fuse was blown because of an accidental ground on the ungrounded side of the circuit, reverse the connections at *L₁L₂* (Fig. 162). This will put the accidental ground on the permanently-grounded side of the circuit, and the circuit will then operate satisfactorily. This method of correcting an accidental ground should be used only in cases where it is necessary that the circuit be quickly put back in service. At the first opportunity the ground should be located and the fault repaired.

221. If The Ground Or Short-Circuit Is On The Circuit-Wiring Proper Or In Fixture Wiring Not Controlled By A Switch, then it cannot be located as explained in Sec. 218.

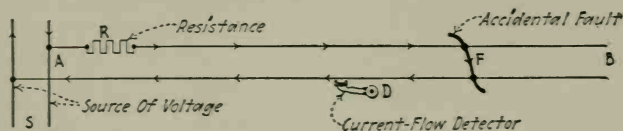


FIG. 163.—Illustrating the principle of locating a fault in a circuit with a "current-flow detector."

In such cases, the procedure which is followed in locating the fault is to connect the wiring to some source of voltage (Fig. 163) and pass a current through the fault. Then, by using some device (Secs. 57 and 229) whereby a current flow can be detected the current is traced to the fault. The amount of current which must be passed through the fault will depend upon the sensitiveness of the current-tracing device. Ordinarily, some sort of resistance must be inserted in the circuit between the source of voltage and the fault to prevent the flow of an excessive current. Various methods of obtaining the

proper current flow and of tracing the current to the fault are explained in following sections.

222. EXPLANATION.—In Fig. 163, a circuit, *AB*, is shown which contains a fault, *F*. When this circuit *AB* is connected to a source of voltage, *S*, a current will flow through the conductors of the circuit and through the fault as indicated by the arrows. The current-limiting resistance *R*, which is inserted in the circuit, is adjusted to control the current flow to within safe values and yet permit a sufficient quantity of current to flow so that it can be readily detected by the current-flow detector, *D*. Now, by means of *D*, it can be determined at any point along the circuit whether or not current is flowing through the wires. On the right of *F* it will be found that no current is flowing and on the left of *F* it will be found that a current is flowing. Hence, by going along the wires *AB* with the current-flow detector *D*, the fault *F* can be located.

223. To Obtain Tracing Current For Locating Faults On Low-Voltage Circuits (440 volts and below), the supply voltage is ordinarily used as the source of voltage (Sec. 221 and Fig. 154). The resistance (*R*, Fig. 163) is usually an incandescent test lamp which, in the case of Edison-plug fuses, is screwed into a fuse receptacle (Fig. 154-II). For

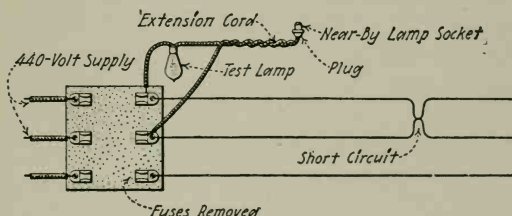


FIG. 164.—Source of voltage obtained from a nearby lamp socket to locate a short-circuit on a 440-volt circuit.

cartridge fuses, the lamp is connected to the fuse clips as shown in Fig. 154. The test lamp or lamps must have a total "series-rating" voltage (Sec. 10) equal to the supply voltage. If the supply voltage is too high for the number of test lamps which are readily available, it is generally feasible to plug an extension cord into a nearby 110-volt lamp socket as shown in Fig. 164. If it is desired to have a large tracing current flow through the fault, several large-wattage lamps may be connected in parallel as shown in Fig. 165. On a 110-volt circuit which has a dead short or ground, a tracing

current of about 5 amp may be obtained by screwing the plug of an electric flat iron (the iron being connected) into the fuse receptacle.

224. One Method Of Locating A Fault By Sectionalizing The Line is illustrated in Fig. 166. A tracing current is per-

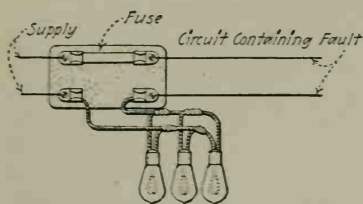


FIG. 165.—Test lamps connected in parallel so that a larger current will flow through the fault.

mitted to flow through the fault, by screwing a lamp into the proper fuse receptacle. All lamp and other energy-consuming devices are removed from the sockets and receptacles. Now begin at the end of the line farthest from the fuse block and cut the line on the supply side of each outlet. When a cut is

made that causes the test lamp to go out, it is known that this cut has isolated the fault from the source of voltage. Therefore, the fault lies between this cut and the one which

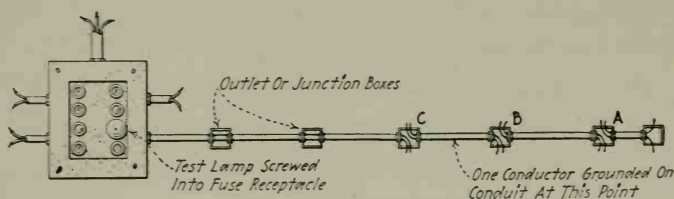


FIG. 166.—Locating a short-circuit or a ground by sectionalizing the line which contains the trouble.

was last made. The disadvantage of this method is in repairing the large number of cuts which it may be necessary to make. If the line can be sectionalized by opening switches or removing fuses, this is a very satisfactory and efficient method of locating faults. See the following example.

225. EXAMPLE.—The fuse on the branch circuit shown in Fig. 166 blew. The defective fuse was removed and a lamp screwed into the fuse receptacle. Because of the fault on the circuit the test lamp burned at full brilliancy. At outlet *A* the canopy was loosened and slipped down and the wires opened. The test lamp was still burning. The same thing was done at box *B* with the same result. However, when box *C* was

opened the test lamp went out, thus indicating that the trouble was between boxes *C* and *B*. After the faulty conductors between *B* and *C* have been replaced with good conductors, each of the cuts at *A*, *B*, and *C* must be spliced.

226. NOTE.—A “TRACING CURRENT” OR “FAULT CURRENT” (See also Sec. 223) is that current which is made to flow through a fault in a circuit for the purpose of locating that fault.

227. A Magneto Can Be Used To Locate A Fault In A Wiring Circuit by sectionalizing the line in the same manner as that which is explained in Sec. 224 for a test lamp. Remove all fuses or open the switch which controls the circuit so that the circuit will be “dead.” Disconnect all energy-consuming devices from the line. Connect the magneto to the dead circuit (Figs. 159 and 161). If the fault is a ground make the connections as shown in Fig. 159. If the fault is a short-circuit connect according to Fig. 161. Then sectionalize the line as explained above (Sec. 224) until the magneto will not ring. Any other test-set device (Div. 1) such as bell and battery or battery and lamp may be used instead of the magneto.

228. The Best Method For Locating A Short-Circuit Or A Ground On An Interior-Wiring Circuit Is To Employ A Tracing-Current Detector whereby the tracing current can be detected without opening the circuit. By this means a person can go along the circuit and test the line at each accessible point (Fig. 163) and locate the fault without making any unnecessary cuts in the line. A tracing-current detector which is particularly convenient and well adapted for this use is the *Shortfinder* (Sec. 57). Since an alternating current of 0.5 amp. can be readily detected through the conductor insulation, a 60-watt lamp connected across the fuse block on a 110-volt circuit will permit ample tracing current to flow. This same device can be used for direct current (Sec. 58). See also the following note.

229. NOTE.—A HOME-MADE TRACING-CURRENT DETECTOR which is sufficiently sensitive to detect a tracing current of about 5 amp. can be made as follows: Make a U-shaped laminated iron core (Fig. 55) about 2 in. long and 0.5 in. wide. Wind about 100 turns of No. 28 or No. 30 B. & S. gage enameled magnet wire around the center of the core. Connect the ends of this winding through a flexible cord to a telephone receiver. When the U-shaped core is held over a wire which is carrying about a 5-amp. alternating current, a buzz can be heard in the receiver.

230. NOTE.—ANOTHER TRACING-CURRENT DETECTOR, which is shown in Fig. 167, consists of a pair of radio receivers. Remove the cap and diaphragm from one of the receivers. This receiver then constitutes the exploring coil. To complete the circuit, connect the two free tips of the cord together. The other receiver is used for listening for the buzz.

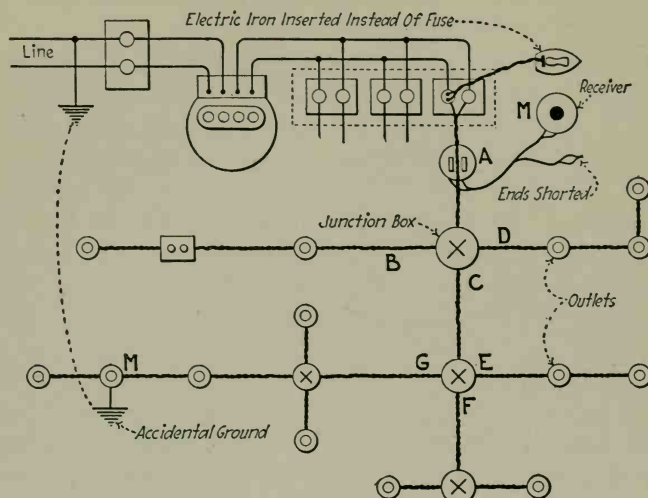


FIG. 167.—Locating a ground or short-circuit with a radio headset. (*Electrical Record*, Dec., 1922.)

Locate the blown fuse and screw an electric iron or a 300-watt test-lamp set (Fig. 165) into the fuse receptacle. Now begin at the panel box and hold the "diaphragmless" or exploring-coil receiver against the wires of that circuit with the receiver poles parallel to the circuit wires (Fig. 167). With the exploring-coil receiver at A, a hum can be heard in the other receiver, M. This indicates that a current is flowing at A. Now proceed to the first junction out on that circuit. No hum will be heard on B or D, but it will be heard on C. Follow the line which produces the hum to the next box. At this point, G will hum but E and F will not. In this manner the humming is followed along the circuit to M. At one side of M there will be a hum whereas at the other side there will be no hum, thereby indicating that the ground or short-circuit is at that point.

231. Normally Ungrounded Circuits Are Nearly Always Equipped With Some Sort Of A Ground Detector.—A circuit which is normally ungrounded will operate just the same with one accidental ground as before the fault occurred. However,

if one accidental ground occurs on one side of the circuit, the insulation resistance is halved and usually in a short time another ground will develop on the other side of the circuit. This of course constitutes a short-circuit and permits an excessive current to flow which burns out a fuse or opens a circuit-breaker. However, if when the ground detector indicates that one accidental ground has occurred, it is immediately located and the fault repaired, the above trouble will not result. Methods of locating grounds on ungrounded circuits are explained in the following sections. For descriptions of ground detectors of various types and a discussion of their principles, see the author's "American Electricians' Handbook" and his "Wiring For Light and Power."

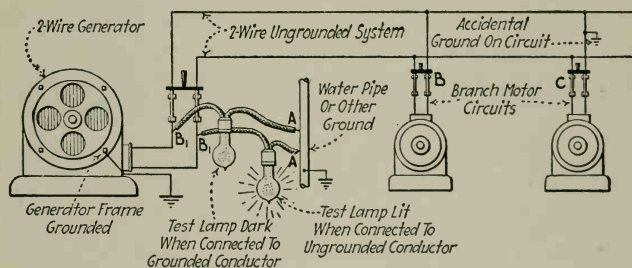


FIG. 168.—Method of locating a ground on an ungrounded system, using a test lamp.

232. NOTE.—IF A NORMALLY UNGROUNDED SYSTEM IS NOT PROVIDED WITH A GROUND DETECTOR, it can be determined whether or not an accidental ground exists by the method shown in Fig. 168. Connect one terminal, A, of the test lamp to a water pipe or other permanent ground. Then touch the other terminal, B, to each conductor of the circuit. If an accidental ground exists, the lamp will light when B₁ is touched to the ungrounded conductor. If there is no accidental ground on the circuit the lamp will not light when touched to any of the conductors.

233. The Most Feasible Method Of Localizing One Accidental Ground On A Normally Ungrounded System is that indicated in Fig. 169. When the ground detector lamp shows a ground somewhere on the system, connect a test lamp to the ungrounded bus. Thus, in Fig. 169 the ground-detector lamp shows that the positive bus is grounded. Therefore the

test lamp is connected to the negative busbar and to ground as shown. Now the lamp will light up to full brilliancy. Open and close each feeder switch *A*, *B* and *C*, in succession. When the switch which controls the circuit that contains the ground is opened, the test lamp will burn at reduced brilliancy. The

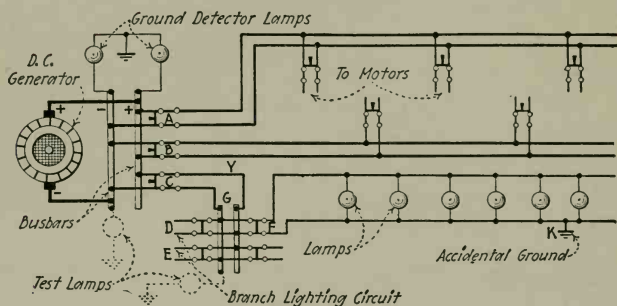


FIG. 169.—Illustrating method of locating a ground on a normally ungrounded circuit. (All protective devices omitted from diagram for simplicity.)

fact that the lamp burns at reduced brilliancy when switch *C* is opened, indicates that the ground is somewhere on that circuit. Next go to the distribution panel, *G*, and connect the test lamp to the negative busbar and ground, and repeat the process. When switch *F* is opened the test lamp burns dimly, thus indicating that the ground is on the branch which is served by *F*. In making the above tests, it is only necessary to open the switch for an instant. After determining that the ground is on branch *F*, it may be located as explained below.

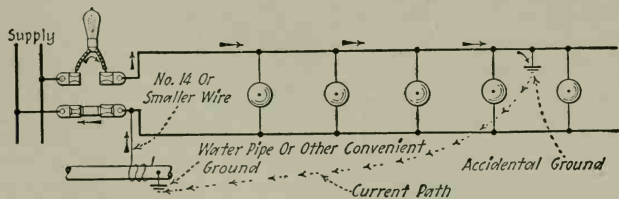


FIG. 170.—Method of establishing a tracing current to locate a ground in a normally ungrounded system.

234. NOTE.—TO LOCATE A GROUND ON A NORMALLY UNGROUNDED CIRCUIT after it has been localized as explained in Sec. 233, proceed as follows: Remove the fuse (Fig. 170) from the conductor which contains the fault. Connect a test-lamp bank across the clips from which

the fuse was removed—or screw a lamp into fuse receptacle. Connect a wire, not larger than No. 14, from the load side of the other fuse to a nearby water pipe or other convenient ground. This will permit a tracing current to flow. The accidental ground can now be located with a tracing-current detector as explained in Sec. 228.

235. Sometimes It May Occur, When Testing To Locate A Ground On An Ungrounded Circuit, That The Instantaneous Opening Of The Switches Will Not Serve To Localize It.—That is, in Sec. 233, the opening of switches *A*, *B*, and *C*, (Fig. 169) will not cause the test lamp to dim. The reason is that the ground is somewhere on the supply side of the switches (Sec. 233)—for example in the generator—or that there are two or more grounds on different circuits on the same side of the system. When this occurs, open all of the switches at the point of distribution as *A*, *B*, *C*. If the test lamp remains bright, the trouble is somewhere on the supply side of this distribution center. See explanation below. If the lamp dims when all switches are open, there are two grounds somewhere on the load side of the switches. Now close each switch in turn until a switch is closed which causes the test lamp to brighten. One of the grounds is somewhere on the circuit controlled by this switch. Before closing any other switches locate the fault on this circuit as explained in Sec. 234, and repair it. Then proceed to locate the other fault or faults in the same manner.

236. EXPLANATION.—Assume that the accidental ground in Fig. 169 was at *Y* instead of at *K*. A test at the busbars, made as explained in Sec. 233, will indicate that the trouble is on the circuit which is controlled by *C*. But when the test is made at the distribution center *G*, the test lamp will not be dimmed by the opening of any switches at *G*. This indicates that the fault is somewhere between *C* and *G*. Then go back to *C* and locate the fault as explained above in Sec. 234.

237. If Two Grounds Develop At The Same Time On Each Side Of A Normally Ungrounded Circuit, an excessive current will flow and a fuse or circuit-breaker will open. If this condition occurs, first locate the ground on the load side of the blown fuse in the same manner as that explained in Secs. 214 to 230, for a permanently grounded circuit. Then locate the other ground as explained above in Secs. 233 and 234.

238. A Short-Circuit On A Normally Ungrounded Circuit May Be Located by the same methods as explained in Secs. 214 to 230 for permanently grounded circuits.

QUESTIONS ON DIVISION 3

1. Name the faults which are likely to occur on an interior-wiring circuit.

2. Explain how such faults can ordinarily be localized to within a small region.

3. What is necessary to enable one to localize faults quickly and effectively by noting the device or devices which do not function properly?

4. What should a circuit directory contain? Where should it be mounted? What is its use?

5. Name five things which may cause open-circuits.

6. Explain how an open-circuit in the circuit-wiring proper may be caused by an accidental ground.

7. What may cause a fuse to rupture when no fault exists on the circuit?

8. What is the maximum value of current which is permitted on a branch lighting circuit by the "National Electric Code?" What should be done if it is desired to use devices which require a current in excess of this value?

9. How may the manner in which an open-circuit manifests itself serve as an aid in its location.

10. What is likely to result if an open-circuit occurs in the neutral of a three-wire lighting circuit?

11. What usually results when an open occurs in one of the conductors supplying a polyphase motor?

12. Explain with a diagram how test lamps may be used on the secondary to indicate an open-circuit in the primary of a three-phase line.

13. Explain with a diagram how an open-circuit in the secondary of a three-phase circuit may result in misleading indications when testing for faults.

14. Make a diagram to explain how to locate a defective fuse with a test lamp.

15. Explain how to locate an open-circuit in a lighting circuit.

16. How may an open-circuit in a conduit run be located with a magnet? Explain with a diagram.

17. Describe a device and explain a method of locating a break in the conductor of an extension cord.

18. Explain a method of locating an open-circuit in a lighting circuit before the service connection has been made.

19. What are three principal causes of blown fuses?

20. Explain with a diagram how to determine what has caused a lighting-circuit fuse to blow.

21. How can it be determined whether the trouble on a circuit is a short-circuit or a ground? Make a diagram to explain.

22. What is the procedure to be followed if a motor fuse blows?

23. How may a short-circuit or a ground in a motor circuit be located? Explain with a diagram. What may be used for this test instead of a magneto?

24. Explain with a diagram how to locate a short-circuit or a ground on a lighting circuit.

25. Make a sketch to explain how the trouble caused by a ground may be temporarily remedied by reversing the connections at the fuse block.

26. Give an explanation of the general principles which are employed in locating a short-circuit or a ground in the circuit-wiring proper.

27. What is the source of voltage which is ordinarily used in locating faults on low-voltage circuits.

28. What kind of a resistance is generally used to limit the current?

29. Explain with a sketch how a fault may be located by sectionalizing the line? What is the greatest disadvantage of this method?

30. Define *tracing current*.

31. Explain how a magneto may be used to locate a fault. Make a sketch.

32. What is the best method of locating a short-circuit or a ground?

33. Explain with a diagram how to locate a fault by means of a tracing current and a tracing-current detector.

34. Describe the construction of two home-made current detectors.

35. What is the function of a ground detector on a normally ungrounded system?

36. Explain with a diagram how to determine whether or not there is a ground on a normally ungrounded system.

37. Explain with a diagram the most feasible method of localizing a ground on a normally ungrounded circuit.

38. After localizing a ground on such a circuit, how may its exact location be determined?

39. What will result if two grounds occur simultaneously on two sides of a normally ungrounded circuit. How can they be located?

40. How can a short-circuit on a normally ungrounded circuit be located?

DIVISION 4

LOCATING FAULTS IN SERIES CIRCUITS

239. Series Circuits are used principally for street lighting. Because of the high voltages which are ordinarily employed, such circuits are seldom carried into buildings. Series street-lighting is usually effected by: (1) *Direct-current arc lamps*, which are fed from a constant-current transformer through a mercury-arc rectifier. (2) *Alternating-current incandescent lamps* which are fed by a constant-current transformer regulator or by a voltage transformer. Each of the above kinds of series circuits are subject to the same faults. Hence any method of locating a fault on one kind is, ordinarily, applicable to the other.

240. The Faults Which Occur On Series Circuits are: (1) *Grounds* (Sec. 241 to 253). (2) *Open-circuits* (Secs. 254 to 261). (3) *Short-circuits* (Sec. 262). Grounds occur more frequently than any of the other faults. Open-circuits seldom develop, and when they do, they will generally be found at a splice, or at a lamp receptacle. Short-circuits seldom occur on series circuits except where duplex cable is used. Methods of locating each of these faults are described in the following sections.

241. A Ground On A Series Circuit (that is, only one ground) will not affect the operation of the circuit. However, if two or more grounds develop on the circuit, then all of the lamps between the grounds will be extinguished. Two grounds on a series circuit are manifested by some of the lamps not burning. Also if the grounds are separated by an appreciable percentage of the total number of lamps on the circuit, the operator at the station will know something is wrong by the change in position of the movable coil on the transformer. Very frequently such transformer stations are automatic and do not have an operator in attendance. In such cases, the

only indication of trouble on the circuit is the report that certain lamps are out.

242. If There Are Two Grounds On A Series Circuit Their Approximate Location May Be Determined by the lamps which are not burning. Thus, in Fig. 171, a circuit of 31 lamps is illustrated. Lamps Nos. 6 to 24 are out. Therefore it is

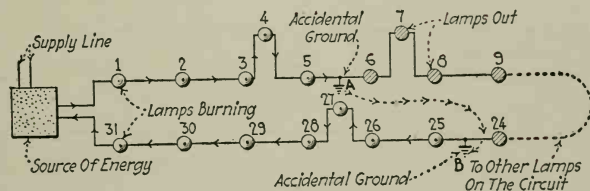


FIG. 171.—Approximate location of grounds on a series circuit may be determined by the lamps which are not burning.

known that one of the grounds which is causing the trouble is somewhere between lamp No. 5 and lamp No. 6, and that the other ground is between lamps No. 24 and No. 25. If the line is overhead, a close inspection of the wiring will usually reveal what is causing the trouble. If the line is buried underground a tone test (Sec. 252) on the wiring between lamps No. 5 and No. 6 and between No. 24 and No. 25 may be necessary to reveal the location of the faults.

243. NOTE.—CONSTANT-CURRENT TRANSFORMER REGULATORS are ordinarily designed to maintain the current constant from full load to practically no load. This does not mean that the energy will not surge if the load is suddenly decreased. For example, if two grounds develop on a 100-lamp circuit so that 90 lamps are suddenly shorted out, the current surge may be sufficient to burn out the other 10 lamps. This surge occurs before the movable coil has time to adjust itself to the decreased load. However, if a sensitive lightning arrester is installed at the station, the voltage surge which is occasioned by the instantaneous decrease in load may discharge across the arrester and prevent the burning out of the 10 lamps. However, if the movable coil is adjusted by hand to the 10-lamp-load operating position before the primary circuit is closed, usually no harm will result.

244. A Ground On A Series Circuit May Be Located Approximately By Voltage Measurements as explained below. For the purpose of explanation, a 25-lamp circuit will be assumed. Each lamp is assumed to have a .50-volt drop.

Neglecting the line drop, the total voltage across the terminals of the transformer would be: $50 \times 25 = 1,250$ volts. Make a chart as indicated in Fig. 172, showing the number and the normal voltage drop corresponding to each lamp. If the line is of considerable length—3 or 4 miles—it may be necessary to

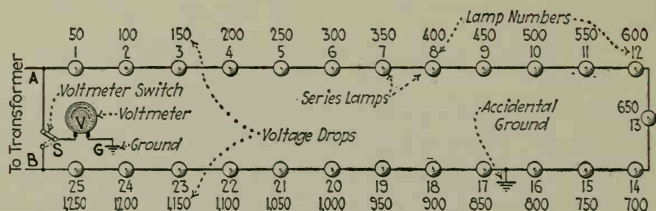


FIG. 172.—Illustrating the voltmeter method of locating a ground on a series circuit.

determine the voltage drop due to the line and add it to the lamp voltage. Now, to provide a ground, *G*, on the line connect a voltmeter, *V*, between line and ground at the transformer as shown. Assume that the voltmeter reading is 800 volts. By referring to the chart which has been made, it is evident that the indicated location of the accidental ground *X*, is between lamps Nos. 16 and 17, because the chart shows 800 volts drop up to lamp 16. As a check, subtract this voltage reading from the total voltage across the transformer terminals. Then change the voltmeter connection to the other side of the circuit, as shown by the dotted lines at, *S*, in Fig. 172, and read the voltage. This reading should be approximately equal to the difference which is obtained by the above subtraction. This method, if properly executed, should locate a ground to within two or three lamps. Its accurate location may then be made as explained in Secs. 246 to 253.

245. NOTE.—IN LOCATING A GROUND BY THE VOLTMETER METHOD, be sure that the voltmeter is connected to the side of the circuit from which the voltages on the chart increase. The proper voltmeter-switch position which connects the voltmeter to this side should be determined and a permanent marking placed thereon. This is to prevent the possibility of a mistake. If a mistake is made in the connection, the indicated location of the ground will be wrong. Thus, suppose the voltmeter in Fig. 172 was connected to *B*. It would read about 450 volts. If it was thought to be connected to *A*, the assumption would be

that the ground was between lamps No. 9 and No. 10; or about 7 lamps from its actual location.

246. A Ground On A Series Circuit May Be Located With A Telephone Receiver And Battery (Fig. 173).—The test set consists of a telephone receiver connected to a battery of two or three dry cells (Fig. 27). The circuit is first disconnected from the transformer at the source. The circuit is then opened

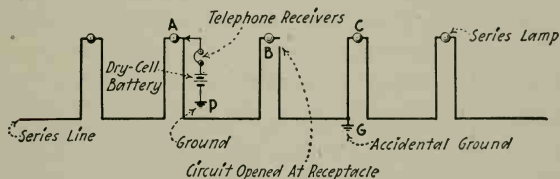


FIG. 173.—Locating a ground with telephone receivers and dry-cell battery.

at a lamp receptacle, and the test applied to one of the lamps adjacent to the one where the circuit is opened. The test is made at the adjacent lamp by grounding one terminal of the test set and touching the other terminal to the conductor of the circuit. If a click is heard in the receiver, the ground and the point of test are on the same side of the open which is made at the receptacle. If no click is heard in the receiver, the open is between the point of test and the ground. See the example below. The method which should be used in opening the circuit at a lamp will depend upon the construction of the receptacle. Also, the point at which the test-set terminal should be touched to the circuit will depend upon the receptacle construction. The test-set ground may be made by touching one terminal of the test set to the sheath of the cable, if it is accessible. Probably the easiest and best way to make the ground is to connect the ground terminal of the test set to an iron rod about $\frac{1}{4}$ in. in diameter and 1 ft. long, and stick the rod into the ground a few inches. It will be seen from the following example that this method will only serve to localize a ground to within the distance between two lamps. See Sec. 250 for a method of locating the exact point where the circuit is grounded.

247. EXAMPLE.—In Fig. 173, the location of the accidental ground *G* is being sought. The troubleman may make the first test at the middle

of the line and proceed by halving the distance (Sec. 167); or, he may begin at the station and test at each lamp as he goes along; or, he may already know the approximate location of the ground from the voltage reading as explained in Sec. 244. The circuit is opened at lamp *B*. The test is made at *A*. No click is heard in the receiver, consequently it is known that *B* is between *S* and the ground, *G*, which is being sought. The circuit is then closed at *B* and opened at *C*. The next test is made at *B*. A click is heard in the receiver. Consequently it is known that the ground on the conductor is somewhere between the two lamps *B* and *C*. It will be found very convenient and result in a great saving of time to employ a helper. The helper works ahead of the tester to open and close the circuit at the lamps. If this method is used on a circuit which has a permanent ground (Sec. 251), the permanent ground must be removed, or the circuit must always be opened between the permanent ground and the point at which the test is to be made.

248. A Ground On A Series-Incandescent System Can Be Located By Using The Voltage Of A Street-Railway System (Fig. 174).—This is done by hooking a wire (*W*, Fig. 174) from

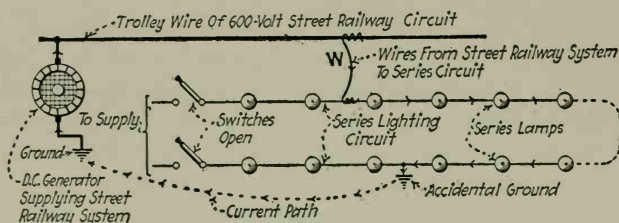


FIG. 174.—Locating a ground on a series lighting circuit by using the voltage from a street railway system.

a nearby street-railway trolley wire to the conductor of the faulty series circuit. Then go along the line and open the series circuit at the lamp receptacles. When opening the receptacles which are located between the trolley-wire connection and the ground—before the ground is passed—a small arc will be drawn when the circuit is opened. After the ground has been passed no arc will be formed. Thus, the ground will be found to be between the two adjacent receptacles at which an arc is obtained and at which an arc is not obtained.

249. NOTE.—THE STREET-RAILWAY VOLTAGE METHOD HAS TWO SOURCES OF DANGER.—One is the working in close proximity to the street railway voltage, which is ordinarily about 600 volts. The other is that if the point where the circuit is connected to the railway trolley happens

to be too close to the ground, the incandescent lamps between that point and the ground will be burned out. For this reason, when the connection is being made, a lamp-bank resistance should be inserted, or, instead, first tap the trolley-wire connection lightly and watch the nearest lamp, to see whether or not it lights up brightly. This method is not to be recommended and should be used only in an emergency.

250. The Determination Of The Exact Location Of A Ground On A Series Circuit depends somewhat on the construction of the line. In any event, the approximate location to within a distance between two adjacent lamps should first be determined by one of the methods as outlined in Secs. 244, 246, or 248. If the line is overhead, a close inspection of the wire between the two lamps will nearly always reveal the trouble. On underground construction, the ground will frequently be at either one or the other of the lamp receptacles, or within the standard. If the cable is spliced to the risers in the standard at the bottom of the standard, examine these splices. If there is any sign of recent digging between the two lamps, the trouble is very likely to be at that point. If the exact location of the fault cannot be found by inspection, apply the tone test as explained in the following section.

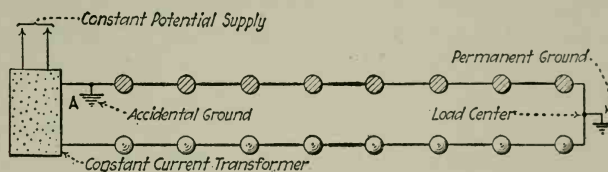


FIG. 175.—Series lighting circuit permanently grounded at the load center.

251. NOTE.—SERIES-LIGHTING CIRCUITS ARE SOMETIMES PERMANENTLY GROUND AT THE APPROXIMATE LOAD CENTER (Fig. 175).—When so grounded, one accidental ground will short-circuit and cause those lamps which are between the permanent and the accidental ground to go out. Thus a ground at A could only cause the lamps between A and G to go out. However, one accidental ground on a circuit which is permanently grounded in the middle cannot cause more than one-half of the lights to go out. If not more than one-half of the lights go out at a time the transformer (Sec. 243) will usually regulate for the sudden change in load without damaging any lamps. If there is no permanent ground on a circuit, the occurrence of one accidental ground can be determined by the voltmeter-to-ground measurement (Sec. 244). Then this one accidental ground can usually be located and repaired before

another accidental ground occurs, thereby, preventing a period of non-operation of some of the lamps on the circuit.

252. The Tone Test On A Series Circuit To Locate A Ground is made in essentially the same manner as on a multiple circuit (Div. 2). The line terminal of the tone-test, set *T*, is connected to the series-circuit conductor (Fig. 176) at one of

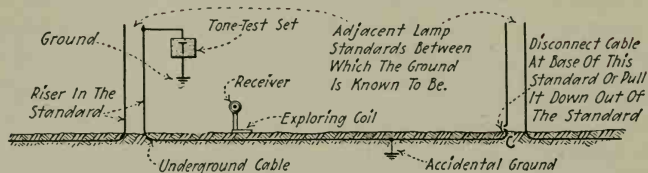


FIG. 176.—Locating, by tone test, the exact spot where the circuit is grounded.

the lamps. The ground terminal of the test set is grounded. The iron-core exploring coil (Div. 1) is carried along over the route of the cable and held as close to the cable as possible. The point at which the tone ceases or decreases materially is where the ground is located. If the cable runs up a standard (or wherever it runs parallel and in close proximity to another portion of the cable), the cable must be cut at the bottom of the standard (*C*, Fig. 176), or it must be disconnected from the receptacle and pulled down out of the standard. If this is not done, the two parallel runs of steel-sheathed cables in the standard will cause the tone to carry by the ground and it will be impossible to locate it. Although not absolutely necessary, it will generally be better if the circuit is opened at each of the lamps between which the ground is located.

253. NOTE.—AN EXCELLENT TONE-TEST SET FOR USE WHERE THE CABLE IS NOT BURIED TOO DEEP IN THE GROUND, is an ordinary direct-current electric bell (Fig. 177) from which the clapper and gong have been removed. The dry-cell battery used with the receiver (Sec. 246) will be sufficient to operate it. One terminal of the battery is connected to one terminal of the bell. The other battery terminal is connected to the circuit conductor. Such an outfit operates at a low voltage and low frequency. Consequently the capacity effect (Sec. 174) is small. The result is that the tone is not as likely to carry by the fault as if a high-voltage high-frequency induction coil test set is used.

254. An Open-Circuit On A Series Circuit Manifests Itself by all of the lamps on the circuit going out. However, (Sec. 261) the fact that none of the lamps on a circuit will burn does not necessarily indicate that there is an open-circuit. Methods of locating purely open-circuits in a series circuit are described hereinafter in Secs. 255 to 261.

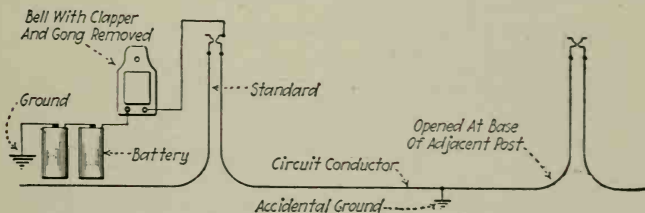


FIG. 177.—Tone-test set, which consists of battery and bell, for locating a ground in a series lighting circuit.

255. An Open-Circuit May Be Located With A Battery And Receiver as indicated in Fig. 178. The line is disconnected from the transformer by opening the switches at the transformer. One terminal of a battery, *B*, which consists

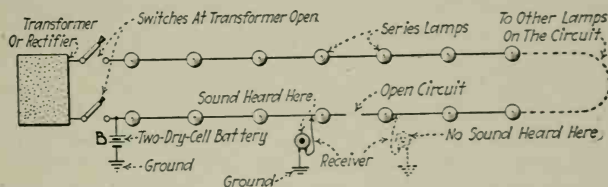


FIG. 178.—Locating an open-circuit with battery and receiver.

of two or three dry cells, is connected to one side of the circuit. The other terminal is grounded. Then the trouble man should go out from the station along that conductor to which the battery is connected. At each point where the conductor is accessible, such as at lamps or pot-heads, ground one terminal of the telephone receiver and touch the other receiver terminal to the conductor. If a click is heard the open-circuit has not yet been reached. When no click is heard the open-circuit has been passed. Thus, in a very short time the open-circuit may be located to within a distance of two lamps. The

exact location of the open-circuit can then usually be determined by inspection.

256. An Open-Circuit May Be Located By Grounding The Line And Then Applying The Supply Voltage From The Line as follows: One side of the circuit is grounded to a water pipe at the station as shown at *G* in Fig. 179. Then, with the sta-

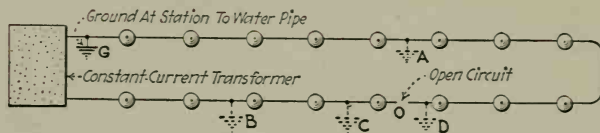


FIG. 179.—Locating a ground with the supply voltage.

tion voltage off, go out on the line, select a point where the conductor is conveniently accessible, and run a wire from this point to a nearby water plug or other convenient ground. Then telephone the station operator and have him close the circuit. Continue doing this until a point is found where the lamps light on one side of the ground thus made. Then make succeeding tests along the line in the direction of the lamps which do not light, until a point is again reached where none of the lamps light. The open-circuit is between this point and the last point of test where the lamps lighted. See the following example.

257. EXAMPLE.—The open-circuit, *O*, in Fig. 179, is to be located by means of the supply voltage. The line is disconnected from the supply and one side of it is grounded to a water pipe *G* in the station. The troubleman goes out on the line to some point, as at *A*, and grounds the circuit to a waterplug by connecting a wire, from a receptacle or a cable terminal at the lamp, to a waterplug. He then calls the station operator over a telephone. The operator then “turns on” the circuit. The troubleman notes that no lamps light. He then telephones the operator to “turn off” the circuit. The troubleman then removes the ground at *A* and goes to some other point on the circuit, as *B*, and repeats the above procedure. Then, when the voltage is impressed on the line, the lamps to the left of *B* are lighted and those to the right of *B* are dark. Going in the direction of the dark lamps, the next trial is made at *C*, with the same result, that is, the lamps to the left are lighted and those to the right are dark. The next ground is made at *D* and no lamps light. This indicates that the open-circuit, *O*, is between *C* and *D*.

258. NOTE.—THE DISADVANTAGES OF THE ABOVE METHOD are: (1) *It ordinarily requires considerable time.* (2) *The circuit is likely to be*

damaged. Unless extreme caution is exercised by the station operator in applying the voltage to the circuit, a number of the lamps are likely to be burned out or an insulation breakdown to ground may be caused.

259. A Method Of Locating An Open-Circuit On A Series System By Using A 110-Volt Supply is illustrated in Fig. 180. This method is particularly applicable to overhead series

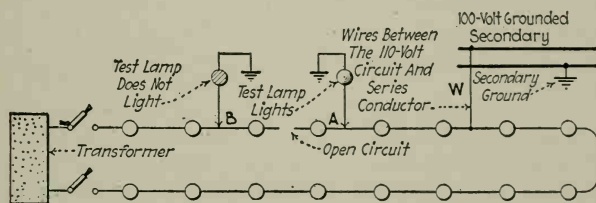


FIG. 180.—Locating an open-circuit in a series system by connecting it to a 110-volt constant-potential grounded secondary.

circuits in outlying residential districts wherein the customers' 110-volt service is frequently carried on the same pole with the street-lighting circuit. Run a wire, *W*, (Fig. 180) from the ungrounded side of a 110-volt grounded circuit to the series-circuit conductor. Then go along the series circuit with a 110-volt test lamp (Div. 1), and with one terminal of the test lamp grounded, touch the other terminal of the test lamp to the series-circuit conductor. If the lamp lights as at *A*, the open-circuit has not yet been reached. If the lamp does not light as at *B*, the open-circuit has been passed. In this way, the location of the open can be exactly determined. As a precaution against a short-circuit of the 110-volt circuit due to an accidental ground, which might be put on the series system, a 110-volt lamp may be connected in the jumper wire, *W*. If this is done, the test lamp will receive something less than one-half normal voltage and, consequently will burn at reduced brilliancy.

260. An Open-Circuit Combined With A Ground Can Best Be Located as though only a ground existed by one of the methods explained in Secs. 241 to 253. If all of the lights on a circuit go out, a test should first be made to determine whether or not a ground exists. This can be done by applying the voltmeter test (Sec. 244), or by applying the receiver and battery

test (Sec. 246) to each of the conductor terminals within the station. If the voltmeter registers or if a click is heard in the receiver, the circuit is grounded. If the voltmeter does not register, or if no click is heard in the receiver, the circuit is not grounded. Of course, to apply the battery and receiver test to a circuit which was permanently grounded, the permanent ground would have to be removed before making the test. In applying the voltmeter test to a permanently grounded circuit, the permanent ground should for positive indication, be removed.

261. NOTE.—THE MERE FACT THAT ALL OF THE LAMPS ON A SERIES CIRCUIT ARE OUT DOES NOT NECESSARILY INDICATE AN OPEN-CIRCUIT. Thus, assume that the circuit shown in Fig. 181 has 200 lamps. An

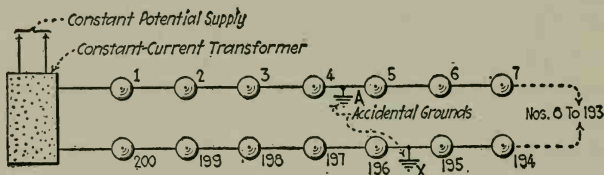


FIG. 181.—Illustrating how some of the lamps on a series circuit may be out when there is no open-circuit.

accidental ground occurs on the circuit at *A*. Then before *A* is removed another accidental ground occurs at, *X*, thus short-circuiting all except 9 (Nos. 1 to 4 and 196 to 200) of the lamps out of the circuit. A sudden decrease from full load to $4\frac{1}{2}$ per cent full load will result in a rush of current which may burn out these 9 lamps before the transformer has time to regulate for the change. Therefore, since 9 of the lamps are burned out and the rest are short-circuited by the two accidental grounds, none of the lamps will burn.

262. Short-Circuits Seldom Occur In Series Circuits, except where the conductors consist of duplex cable. Even in this case, a short-circuit without an accompanying ground is a rare occurrence. If a short-circuit and a ground occur, the fault may be located, as though only a ground existed, by the telephone receiver and battery, as explained in Sec. 246. However, if a short-circuit only develops, it may be located by going along the line and observing the lamps. If some of the lamps are lighted (Fig. 182) and some are dark, the short-circuit, *S*, will be between the last lamp *A* which is lighted and

the first lamp *B* which is out. If a short-circuit results in the burnout of all of the lamps between the short-circuit and the station, begin at the station and examine each lamp along the line until a good lamp is found. This will be lamp *B* (Fig. 182).

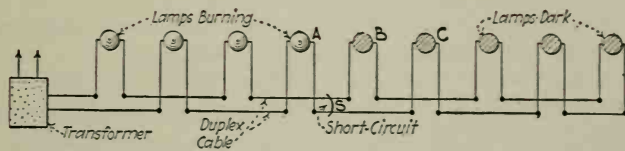


FIG. 182.—Locating a short-circuit in the duplex cable of a series lighting circuit.

The short-circuit will usually be between the last burned-out lamp and the first good one. This may not always be successful because lamp *B* (Fig. 182) might have been burned out before the short-circuit occurred. Then if lamp *C* was good, one would erroneously assume that the fault was between *B* and *C*.

QUESTIONS ON DIVISION 4

1. For what purpose are series circuits generally used?
2. Why are series circuits not frequently carried into buildings?
3. By what two methods is series street-lighting usually effected?
4. What are the faults to which series circuits are subject?
5. What effect does one ground have on the operation of a series lighting circuit?
6. What effect do two grounds have on the operation of a series circuit?
7. How are two grounds manifested?
8. Explain with a diagram how two grounds may be approximately located by observing the lamps on the circuit?
9. What is likely to happen if a large percentage of the lamps on a series circuit are suddenly shorted out? Explain how this may sometimes be prevented?
10. Explain with a diagram how a ground may be located by voltage measurement. What precaution must be observed to prevent an error in the location?
11. Explain with a diagram how a ground may be located with a battery and receiver.
12. How may a ground be located by using the voltage of a street railway? What are the disadvantages of this method?
13. How is the exact spot determined at which a ground on an overhead line exists? On an underground line?

14. Make a diagram to explain how the exact location of a ground on a buried cable may be determined by the tone test. What kind of tone-test apparatus is especially suitable for this service? When the tone test method is used what must be done to the riser at the next lamp standard?

15. How does an open-circuit manifest itself?

16. Explain with a diagram how an open-circuit may be located by using a battery and receiver.

17. Explain with a diagram how an open-circuit may be located by impressing the voltage of the transformer on the circuit. What are the disadvantages of this method?

18. How can an open-circuit combined with a ground best be located?

19. What else besides a ground may cause all of the lamps on a circuit to be out?

20. When all of the lights on a circuit are out, what should be done before an attempt is made to locate the trouble?

21. What kind of series-circuit construction may develop short-circuits?

22. Explain two methods of locating a short-circuit on a series circuit.

DIVISION 5

INSULATION RESISTANCE

263. Insulation Resistance is the resistance which an insulating material offers to the flow of electricity. No substance is a perfect *insulator*. That is, no material will absolutely prevent a current flow between two points in it if the two points

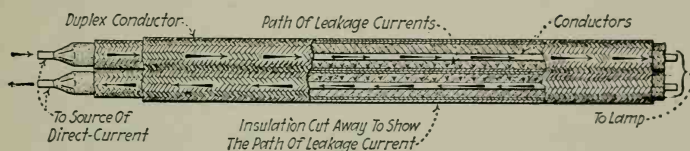


FIG. 183.—Leakage of direct current flowing through the insulation on a duplex conductor. The amount of this leakage current is determined by the "insulation resistance" between the two wires. (Arrows indicate direction of current flow.)

are subjected to a voltage (difference of potential). Thus, if a current is flowing to and from an electric lamp through the two wires of a duplex rubber-covered wire (Fig. 183) there is also some (an exceedingly small) current flowing from one wire to the other through the rubber. If the insulation resistance of the insulation is high, the amount of *leakage current* which thus flows through the rubber will be small. If the insulation resistance becomes low this current will increase. Many electric circuits have one of their conductors permanently grounded (Fig. 184) at one or more points. Consequently, at every point on the ungrounded conductor there is a tendency for the current to leave the ungrounded conductor and flow to the ground. It is prevented from doing this to any appreciable extent by the insulation. Often this insulation is the surrounding air.

264. NOTE.—INSULATION RESISTANCE IS USUALLY MEASURED IN "MEGOHMS," see Sec. 62 for definition.

265. The Condition Of Electrical Insulation Can, To A Certain Extent, Be Determined By A Measurement Of Its Resistance; that is, by a measurement of its insulation resistance. If the insulation resistance of an electric circuit

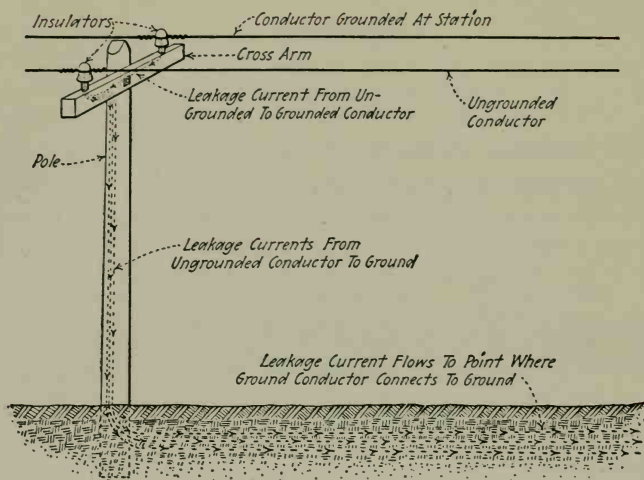


FIG. 184.—Diagram showing leakage currents flowing from ungrounded conductor of a system with one of its conductors permanently grounded.

gradually decreases, it will, probably, eventually break down entirely. Consequently, if it is known that the insulation is beginning to get weak, the cause (Sec. 275) can frequently be determined and removed, thus preventing the breakdown. If the cause cannot be removed, a new piece of good apparatus or material may be installed in place of the faulty part, and thereby prevent a service interruption. Various causes of weak insulation, the methods of measuring insulation resistance, and the methods of locating the faulty portion are described hereinafter in this division.

266. Periodic Measurements Of The Insulation Resistance Of Electric Circuits And Apparatus should be made (Fig. 185). By plotting the values obtained by the measurements, and noting the temperature of the apparatus, duration of run, and atmospheric conditions, the condition of the circuit or apparatus can be accurately supervised. The more important it is to have a certain machine, or piece of apparatus always

ready for service, the more necessary are periodic tests of the insulation resistance of such apparatus. A generator which is needed to carry the peak load, a power feeder, feeding an important industry, or a motor driving a ventilating fan for a mine, on which time lost due to a burn out or failure would be serious, should be carefully watched. If incipient trouble is

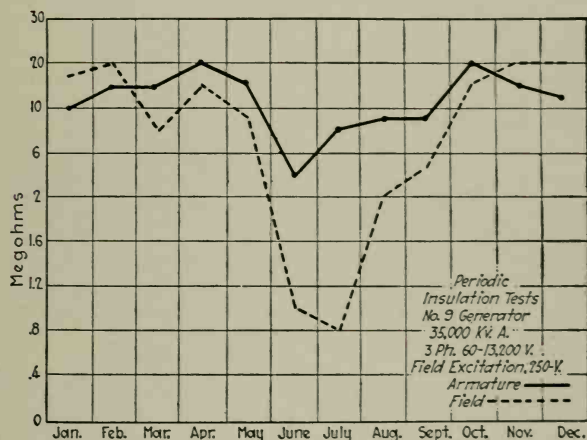


FIG. 185.—Periodic insulation tests on a 35,000-kva. 3-phase, 60-cycle, 13,200-volt generator. Field excitation was 250 volts. (From *James G. Biddle, Cat. No. 985.*)

detected and can be promptly remedied, the chances of a complete breakdown or failure of the insulation are thereby made negligible. But where it is impossible to take the apparatus out of service to make the necessary repairs and the trouble increases, the true condition will be realized if insulation resistance records are maintained. Then provisions for prompt renewals can be made before a failure occurs. This will prevent a prolonged tie up of the apparatus.

267. NOTE.—TO OBTAIN BEST RESULTS FROM PERIODIC INSULATION-RESISTANCE MEASUREMENTS, THEY SHOULD BE MADE AT LEAST ONCE A MONTH.—Under adverse operating conditions such as moisture, presence of acid fumes, dirt, oil, etc., the measurements should be made more frequently, say every week or every two weeks.

268. The Properties Of Electrical Insulations May Be Classified as follows: (1) *Its resistance to the passage of*

electric current, (insulation resistance). (2) Its dielectric strength against breakdown under static strain. The resistance of a perfectly homogeneous insulating material is directly

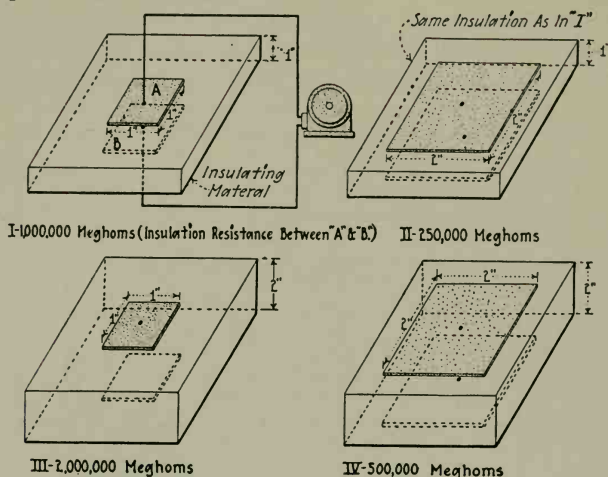


FIG. 186.—Examples showing how insulation resistance varies with the thickness of the insulation and the area of the plates.

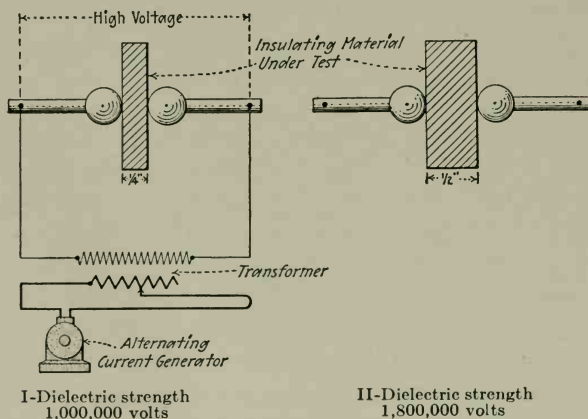


FIG. 187.—Illustrating a dielectric-strength or high-voltage test and showing how dielectric strength varies with the thickness of the insulating material.

proportional to the thickness (Fig. 186) and inversely proportional to the area of the material which is subjected to voltage. The dielectric strength of an insulating material is its ability to withstand voltage puncture. This value is not necessarily

high in a material having high resistance. The dielectric strength is not affected by the area of insulation. It does, however, increase (Fig. 187) with an increase in thickness of the insulation, but not necessarily in direct proportion.

269. NOTE.—THE RESISTANCE OF INSULATING MATERIAL is usually expressed as the number of ohms resistance between two opposite faces of a cube of the material. The cube which is ordinarily used is an inch cube or a centimeter cube, that is, a cube which is 1 in. or 1 cm. on a side. This value, when expressed in *ohms per centimeter cube* is called the *resistivity*. Following are resistivities, all expressed in ohms per centimeter cube, of some common insulating materials: bakelite, 5×10^{11} ; ordinary glass, 9×10^{13} ; mica, 0.04 to 200×10^{15} ; paper, 5×10^4 ; porcelain, 3×10^{14} .

270. NOTE.—DIELECTRIC STRENGTH IS USUALLY MEASURED IN VOLTS PER MIL THICKNESS; a "mil" is $\frac{1}{1,000}$ in. Some examples, for different material are: asbestos paper, 100; bakelite, up to 800; celluloid, 500; linen empire cloth, 1,350; canvas empire cloth, 775; fiber, 75 to 425; ordinary glass, 225; mica, 625; plate micanite, 950; paper, 220; porcelain, 200; oiled pressboard, 1,000; hard rubber, 1,750; slate, 33. Each of the above approximate values are expressed in volts per mil thickness.

271. A Measurement Of Insulation Resistance Is Of More Real Importance Than A Dielectric-Strength (High-Voltage) Test, particularly as it can be readily made from time to time during the life of the apparatus. It does not take the place of the high-voltage test, which is to determine the dielectric strength. However, the insulation-resistance measurement should be made before the dielectric-strength test. This provides a safeguard against failure due to leaks while subjecting the apparatus to the high voltage. The insulation-resistance measurement should be repeated after the high-voltage test to ascertain whether or not the insulation has been permanently weakened (Sec. 272) by the application of the high voltage. Insulation-resistance tests should also be made after installation and before the apparatus is put into service, and periodically (Sec. 266) during the life of the apparatus, to determine if it is safe and not liable to sudden failure. It is more important for the apparatus to stand up under service conditions, than it is for it simply to have endured an initial test to determine its ability to withstand a certain dielectric stress at that time.

272. The Dielectric Strength Of Insulating Material Is Reduced By Prolonging The High-Voltage Tests.—The graph of Fig. 188 shows graphically the effect, in percentage of the 1-min. rating, when the high-voltage test on a dielectric is prolonged beyond the standard period of 1 min. which is

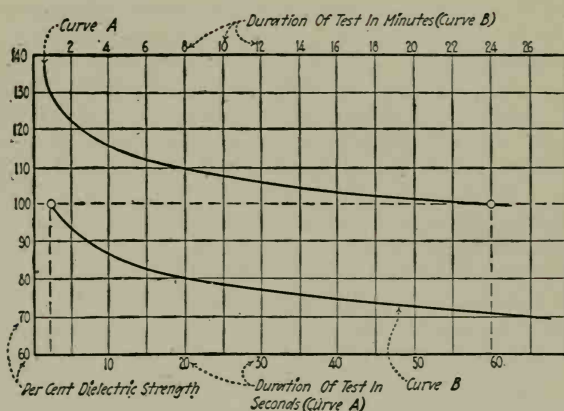


FIG. 188.—Graph showing the effect of prolonging a high-voltage test on the dielectric strength of insulating oil. This shows the oil will withstand a voltage almost 40 per cent higher for 1 sec., than it will for 1 min. (*Electrical World*.)

specified by the "A. I. E. E. Standards." The tests of Fig. 188 were made on transformer oil at 75° C. The curves may be expressed by the formula:

$$(52) \quad G = 100 - 21 \log_{10} T \quad (\text{per cent})$$

Wherein: G = the per cent dielectric strength, on the basis that the insulation which is tested 1 min. has 100 per cent strength at the end of the test. T = the duration of the test in minutes.

273. EXAMPLE.—If a transformer oil has a dielectric strength of 1,000 volts per mil thickness under a 1-min. test, by For. (52), it would if tested for 20 min. withstand $(100 - 21 \log_{10} 20)$ per cent of 1,000 volts. Since $100 - 21 \log_{10} 20 = 100 - 21 \times 1.303 = 100 - 27.3 = 73.6$ the dielectric strength under a 20-min. test would be 73.6 per cent of 1,000 or 736 volts per mil.

274. The Temperature Coefficient Of Insulation Resistance Is Negative And Numerically Large.—That is, as the tempera-

ture increases, the insulation resistance decreases. Even for a small increase in temperature, the insulation resistance decreases greatly. Therefore, it is imperative to make note of the approximate temperature of any apparatus when tested. Results of a test on a 1,000,000-cir. mil lead-covered, 650-volt underground railway feeder is graphically recorded in Fig.

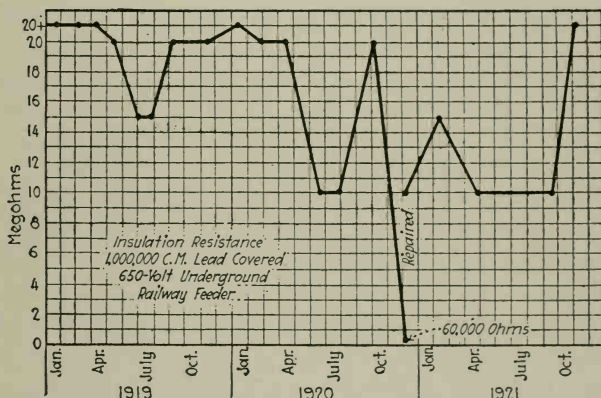


FIG. 189.—Graph showing the results of a test covering a period of 3 years on a lead-covered, paper-insulated, 650-volt railway feeder. The location is in a city on the Great Lakes. It will be noted that the insulation resistance falls in the summer with the higher temperatures in the ducts. (Cat. 987, James G. Biddle.)

189. The location was in a city on the Great Lakes. It is interesting to note how the insulation resistance falls in the summer with higher temperature in the ducts. On Dec. 8, 1920, electrolysis reduced the insulation resistance to 60,000 ohms, but the trouble was then located and remedied before the insulation broke down.

275. Excessively High Temperature Affects The Insulation Resistance Of The Windings Of Electrical Apparatus.—If the temperature rise is sufficient to char the insulation, breakdown nearly always follows immediately. However, excessive heat may cause the insulation to crack without charring it. With cracked insulation the machine may continue to operate for a time without any apparent trouble. When in such condition, a measurement of the insulation resistance will show a decrease in its value. This decrease, which is caused by these minute

cracks accumulating moisture and dirt, is usually followed by a breakdown.

276. NOTE.—THE INSULATION RESISTANCE OF RUBBER INSULATION 60° F. may be from 13 to 108 times greater than at a temperature of 104° F. ("Handbook," STANDARD UNDERGROUND CABLE CO.).

277. Low Insulation Resistances Are Frequently Caused By Moisture Or Green Insulation.—"Green" insulation is insulation, such as insulating varnish, which has not been completely dried. To correct this cause of low resistance,

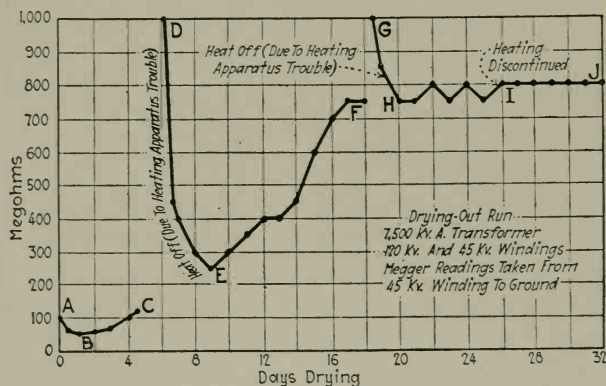


FIG. 190.—Insulation-resistance measurement for determining the condition of the insulation of a transformer winding during the process of drying-out prior to its submersion in oil. (From James G. Biddle, Cat. No. 985.)

the apparatus should be dried or baked until the insulation resistance has attained a proper value. It must be remembered (Sec. 268) that the insulation resistance of the entire circuit is less than the insulation resistance of any of the separate parts. The greater the extent of a circuit, the greater will be the "area" of its insulation which is subjected to voltage; in Sec. 268 it is explained that insulation resistance decreases directly as the area increases. Apparatus which has been idle for a considerable length of time or which has been repaired, should be treated the same as though it were new, and should be baked before it is put into operation.

278. Insulation-Resistance Measurements Taken From Time To Time During The Process Of Drying Out The

Windings Of An Electrical Machine Will Indicate Its Condition.—Figure 190 shows a graphic representation of the results obtained while drying out a large transformer before submerging it in oil. It will be noticed from the graph that considerable moisture was present, at the beginning of the bake. This is evidenced by the comparatively low insulation resistance at that time. The insulation resistance at first decreased (*A* to *B*) as the temperature increased (Sec. 274). Then it increased (*B* to *C*) as moisture was driven off. Complete dryness is shown by the insulation resistance becoming constant at *H* to *I*. Then as the transformer was permitted to cool, due to a failure of the heating apparatus, the insulation resistance increased from *C* to *D*. Further application of heat reduced the insulation resistance from *D* to *E*. As more moisture was driven off the insulation resistance increased from *E* to *F*, and so on.

279. Table Showing The Values Of The Insulation Resistance Of Machines, Excluding Oil-Immersed Apparatus, As Specified By The "A. I. E. E. Standards, 1922."

Rated voltage of machines	Megohms		
	100 Kva.	1,000 Kva.	10,000 Kva.
100	0.091	0.05	
1,000	0.91	0.50	0.091
10,000	9.1	5.00	0.91
100,000		50.00	9.1

280. The Insulation Resistance Of A Machine At Its Operating Temperature Shall Not Be Less Than That Given By The Following Formula.—("A. I. E. E. Standards, 1922").

(53) *Insulation resistance in megohms =*

$$\frac{\text{Voltage at terminals}}{\text{Ratings in kva.} + 1,000}$$

The above formula applies only to "dry" apparatus. Such high values are not obtainable in oil-immersed apparatus.

281. EXAMPLE.—What is the minimum permissible insulation resistance of a 25,000-kva., 6,600-volt generator, to conform to the "A. I. E. E. Standards"? **SOLUTION:** By For. (53) (2), *Insulation resistance in megohms* = (Voltage at terminals) ÷ (Rating in kva. + 1,000) = 6,600 ÷ (25,000 + 1,000) = 0.25 megohms, or 250,000 ohms.

282. NOTE.—THE MINIMUM PERMISSIBLE INSULATION RESISTANCE AS REQUIRED BY THE "A. I. E. E. STANDARDS" (Table 279) is considerably smaller than that which is found on good machines in operation. The author recently had occasion to measure the insulation resistance of a 100-volt, 50-kva. direct-current generator. This particular machine had an insulation resistance of approximately 100 megohms, whereas 0.091 megohms would have been within the specification of the above table.

283. Insulation-Resistance Measurements Are Used By At Least One Insurance Company To Determine The Condition Of The Insulation Of The Apparatus To Be Insured.—*The Hartford Steam Boiler Inspection And Insurance Company*, uses the insulation-resistance method for determining the insulation condition of a motor or generator, or of any other electrical equipment which it insures. The insulation resistance is determined by the use of a Megger similar to the type described in Sec. 63. Periodic tests are made during the term of the policy, at intervals of approximately every four months. Should the insulation resistance of a device decrease abnormally in a brief period of time, the policy holder is informed of the conditions of the apparatus. He is then required to make the necessary repairs which will bring the insulation resistance of the machine back to normal. Otherwise the insurance of the machine or device is suspended.

284. The Insulation Resistance Between All Conductors And Between All Conductors And Ground, of a completed interior-wiring installation, as specified by the 1923 "National Electrical Code," is given in Table 286. The values therein given should be determined with all cutouts and safety devices in place. If lamp sockets, receptacles, fixtures and other appliances are also connected, the minimum resistance required shall be one-half of that specified in the table.

285. NOTE.—THE AMPERE RATING IN THE FOLLOWING TABLE is the ampere rating of the fuse next back on line which is being considered. Thus, a circuit fused with a 25-amp. fuse would, if the sockets, receptacles

and fixtures were connected, be required to have an insulation resistance of 400,000 ohms.

286. Table Showing The Minimum Resistance Between Conductors And Between All Conductors And Ground In An Interior-Wiring Installation, as specified by the "National Electrical Code."

Amperes	Ohms
5	4,000,000
10	2,000,000
25	800,000
50	400,000
100	200,000
200	100,000
400	50,000
800	25,000
1,600	12,000

287. The Insulation Resistance Of Rubber-Covered Wire May Be Determined by the method diagrammed in Fig. 191.

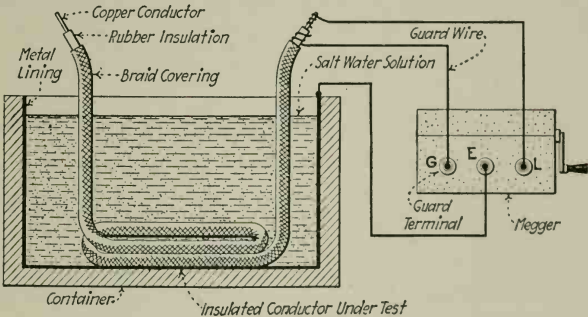


FIG. 191.—Method of measuring the insulation resistance of a conductor.

The insulated wire is first immersed in a tank of water for about 24 hr. to permit the insulation to become thoroughly saturated. Then, connections are made to the wire and the metal lining

of the tank as shown in Fig. 191. By turning the crank on the instrument, a deflection of the galvanometer pointer will be noted, the scale of which is calibrated to read directly in megohms. The function of the guard wire which connects to the guard terminal *G* is explained in Sec. 313.

288. NOTE.—THE INSULATION RESISTANCE OF CONDUCTORS AND CABLES IS STATED IN "MEGOHMS PER UNIT LENGTH."—As cables vary in length it is obviously useless, for purposes of comparison, to know the insulation resistance of a cable without also knowing its length. Hence it is usual to speak of the resistance per unit of length, as the insulation resistance per mile, of a given cable. Thus, the values obtained in Sec. 287 should be reduced to these terms.

289. EXAMPLE.—If a cable which is $\frac{1}{8}$ mile long had an insulation resistance of 3,200 megohms, it would have an insulation resistance of: $\frac{1}{8} \times 3,200 = 400$ megohms per mile.

290. "The Insulation Resistance Of Each Conductor Of A Multi-Conductor Cable Shall Be The Insulation Resistance Measured From Each Conductor To All The Other Conductors In Multiple With The Sheath Or Water." (Rule 9,323, "A.

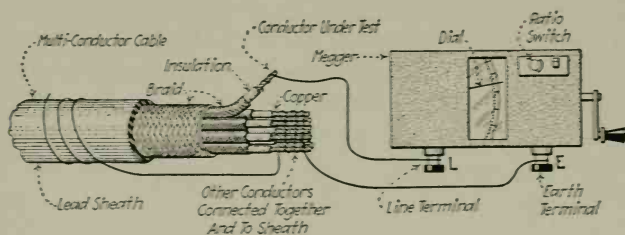


FIG. 192.—Method of testing one conductor of a multi-conductor cable.

I. E. E. Standards, 1922").—Figure 192 shows the method of measuring the insulation resistance of a conductor of a multi-conductor cable. All of the conductors, except the one to be tested, are bound together at one end and then to the lead sheath with a wire. At the other end of the cable the conductors are left separate from each other. The conductor to be tested should be connected to the "line" terminal (*L*, Fig. 192) of a suitable insulation-resistance measuring device, and the "earth" terminal, *E*, of the device should be connected to the

sheath and to the bunched conductors of the cable which is under test.

291. A Magneto Testing Set May Be Used To Obtain A General Idea Of The Insulation Resistance Of A Circuit, (Figs. 193 and 29; see also Sec. 21).—The set consists of a hand-driven alternating-current generator *G*, connected in

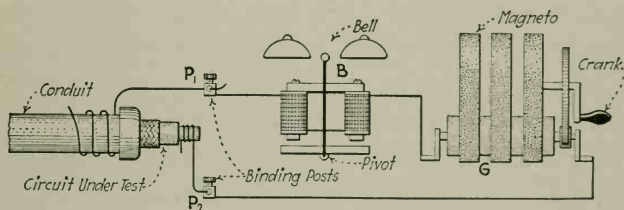


FIG. 193.—Using a magneto testing set to determine the approximate insulation resistance of a circuit.

series with an alternating-current bell, *B*, and suitable binding posts *P*₁ and *P*₂. The circuit which is to be tested is connected to the binding posts of the set. Then the armature of the generator is rotated by means of a crank, thereby generating an alternating electromotive force. This sends a current through the circuit and rings the bell, provided the resistance of the circuit is within the range of the testing set. Knowing the highest resistance through which the magneto testing set will ring (Sec. 21), the loudness of the ringing is a rough indication of the resistance of the circuit being tested.

292. EXPLANATION.—(This “explanation” applies only to circuits which are practically non-inductive and which contain practically no *capacity*; for inductive and capacity circuits see following note and Sec. 20). If the testing set is designed so that it will ring through a resistance of 100,000 ohms, it can be determined whether the resistance of a circuit is greater or less than 100,000 ohms. When the bell rings almost as loudly and the crank turns almost as “heavily” when testing a circuit as when the binding posts of the set are short circuited, it indicates that the resistance of the circuit is low. If the bell rings only feebly, it shows that the resistance of the circuit is somewhere near the maximum range of the set. When the bell does not ring at all, it indicates that the resistance of the circuit is higher than the range of the magneto. In this case the magneto should be tested for ringing by shorting the binding posts of the set.

293. NOTE.—THE MAGNETO METHOD OF DETERMINING INSULATION RESISTANCE IS NOT APPLICABLE TO LONG LINES.—This is because the capacity effect of such a line will frequently permit sufficient current to flow to ring the bell, regardless of how high the insulation resistance may be.

294. Insulation Resistance Can Be Measured With An Ordinary Direct-Current Voltmeter (Fig. 194).—The resistance of the voltmeter must be known. The instrument should be of a high-resistance type, preferably about 100 ohms per

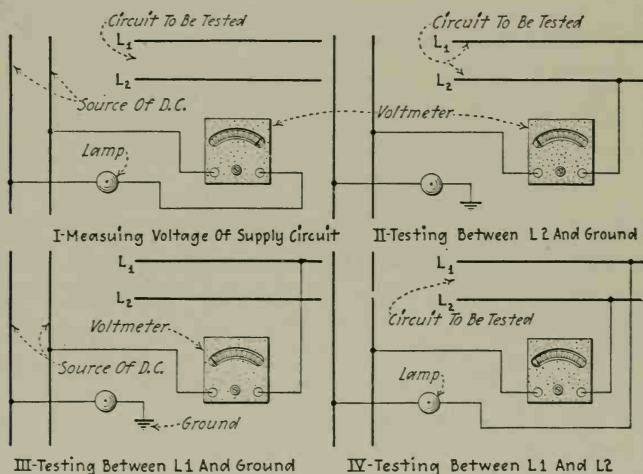


FIG. 194.—Measuring the insulation resistance of a circuit by the voltmeter method.

volt. The resistances of all portable voltmeters are ordinarily recorded on the card which is attached in the cover on the case. Direct-current voltmeters only are suitable for this service because the scale division, for the low values, on alternating-current voltmeters are so wide that it is not possible to make reasonably accurate measurements with them. A source of direct-current voltage (Fig. 194) must be available for making the measurement. The higher the voltage, within reasonable limits, the better; a 500-volt source is much better than a 110-volt source. Ordinarily, a pressure of at least 500 volts is necessary for determining the insulation resistances of circuits or machines—the readings given with lower voltages are so

low on the voltmeter scale that they are scarcely decipherable, if at all. The specific directions are given hereinafter.

295. To Measure The Insulation Resistance Of A Circuit By The Voltmeter Method proceed as follows: With a lamp connected in series with the voltmeter (Fig. 194-I) note the deflection when connected across the supply voltage. Call this value V . The insulation resistance of conductor L_1 or conductor L_2 to ground can be determined by noting the deflection of the voltmeter when it is connected, respectively, as shown in Fig. 194-II and III, and letting the volts value obtained in either case be represented by V_1 . Then, by substituting the known values of the symbols in the following formula, the insulation resistance, R , of either line, L_1 or L_2 , can be computed.

$$(54) \quad R = R_1 \left\{ \frac{V}{V_1} - 1 \right\} \quad (\text{ohms})$$

Wherein: R = Insulation resistance of circuit being measured, in ohms. R_1 = Resistance of the voltmeter, in ohms. V = Line voltage, in volts, as obtained in Fig. 194-I. V_1 = Voltage recorded on voltmeter when it is connected in series with circuit, the insulation resistance of which is to be measured, as in Fig. 194-II and -III.

296. EXAMPLE.—It was observed that the values indicated by a voltmeter when making the necessary measurements to determine the insulation resistance of a circuit were as follows: $V = 212$ volts, $V_1 = 4$ volts, and the resistance of the voltmeter was 24,760 ohms. **SOLUTION.**—

By For. (54), *The insulation resistance of the circuit*, $R = R_1 \left(\frac{V}{V_1} - 1 \right) = 24,760(212 \div 4 - 1) = 24,760(53 - 1) = 1,287,520$ ohms. The insulation resistance of a circuit is usually expressed in megohms. Since one megohm is equal to 1,000,000 ohms, thus 1,287,520 ohms would be expressed as 1.29 megohms.

297. NOTE.—THE LAMP (Fig. 194) IS USED IN THE VOLTMETER METHOD OF MEASURING THE INSULATION RESISTANCE OF A CIRCUIT AS A PRECAUTION AGAINST ACCIDENTAL SHORT-CIRCUITS.—The number of lamps which should thus be connected in the circuit will depend upon the voltage of the supply circuit. For a circuit of 110 volts, one 110-volt lamp will be sufficient, while for a 220-volt circuit, two 110-volt lamps connected in series should be used. On a 500-volt circuit, five 110-volt lamps connected in series should be used. The voltmeter in either case should have a range which is at least as great as that of the

supply-voltage circuit. This is to avoid the possibility of accidentally burning out the windings of the instrument.

298. To Determine The Maximum Resistance That Can Be Accurately Measured With A Voltmeter, the following formula may be employed (it is assumed that the direct-current voltage employed will always be sufficient to deflect the voltmeter needle to its full range).

$$(55) \quad X = \frac{R \times O}{D} \quad (\text{ohms})$$

Wherein: X = Maximum resistance which can be accurately measured with the voltmeter under consideration. R = Range of voltmeter, in volts. O = Resistance of voltmeter, in ohms. D = Value, in volts, of the smallest division on the voltmeter which can be accurately read.

299. EXAMPLE.—What is the maximum resistance which can be accurately measured with a 500-volt voltmeter which has a resistance of 50,000 ohms and which has 5-volt scale graduations? **SOLUTION.**—Substituting in For. (55): $X = R \times O \div D = 500 \times 50,000 \div 5 = 5,000,000 \text{ ohms} = 5 \text{ megohms}$.

300. EXAMPLE.—What maximum resistance can be accurately measured with a 110-volt voltmeter which has a resistance of 10,000 ohms and 1-volt graduations? **SOLUTION.**—Substituting in For. (55): $X = R \times O \div D = 100 \times 10,000 \div 1 = 1,000,000 \text{ ohms} = 1 \text{ megohm}$.

301. The Most Convenient And The Quickest Method Of Measuring Insulation Resistance Is With An Instrument Which Is Designed Primarily For That Purpose.—Instruments of this type, such as the *Megohmer* and the *Megger* (Secs. 302 and 306), are calibrated to read directly in ohms or megohms, and require no outside source of voltage. These instruments are described in Div. 1; methods of using them are explained in the following sections.

302. To Measure Insulation Resistance With The Model "D" Megohmer (Fig. 195) proceed as follows: The instrument should first be placed on a firm base and as near level as is practical. If the insulation resistance to ground of a conductor is to be measured, connect the terminal marked E to the ground and the terminal marked K to the conductor to be tested. The push button P is pressed and the generator crank rotated until the instrument pointer stands at the zero point

on the megohm scale. The generator voltage can be determined by noting the position of the pointer over the voltmeter scale. The correct voltage is obtained at about 180 r.p.m.

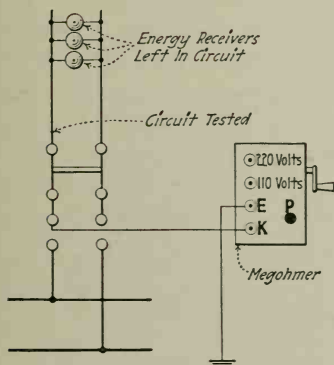


FIG. 195.—Connections for measuring the insulation resistance of a system. (Herman H. Sticht Co., New York, N. Y., Bull. No. 125.)

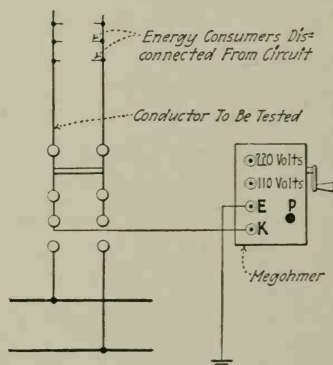


FIG. 196.—Connection for measuring the insulation resistance of one conductor of a circuit. (Herman H. Sticht Co., New York, N. Y., Bull. No. 125.)

of the crank. Continue to rotate the crank at the same speed and simultaneously release the push button. This permits the current to pass through the conductors of the system and through the insulation resistance to ground. The insulation resistance can now be determined by noting the position of the pointer on the megohm scale. Figure 196 illustrates the method of measuring the resistance of one conductor to ground. The connections for measuring the insulation resistance between two conductors of a circuit are shown in Fig. 197. The operating principle of the Model "D" Megohmmeter is explained in Sec. 71.

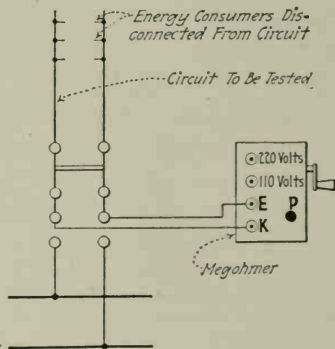


FIG. 197.—Connections for measuring the insulation resistance between the conductors of a circuit. (Herman H. Sticht Co., New York, N. Y., Bull. No. 125.)

303. The 2 In 1 Megohmer Can Be Used To Measure Voltage, on either alternating- or direct-current circuits, of either 110 or 220 volts difference of potential. To make a voltage measurement open link switches L_1 and L_2 , (Fig. 198).

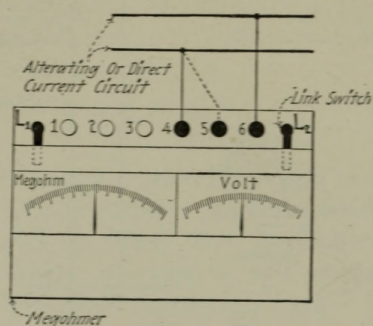


FIG. 198.—Connection of "2 in 1" megohmmeter for voltage measurements. Both link switches should be open in making voltage measurements. For circuits operating at pressures up to 110 volts connect to terminals marked 5 and 6, and for circuits operating at pressures up to 220 volts connect to terminals marked 4 and 6. (Herman H. Sticht, New York, N. Y., Bull. No. 125.)

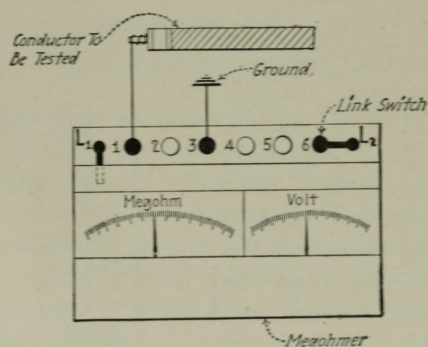


FIG. 199.—Connections of "2 in 1" megohmmeter for insulation resistance measurement. Link L_1 should be open and link L_2 closed, and the resistance under measurement should be connected to terminals marked 1 and 3. (Herman H. Sticht Co., New York, N. Y., Bull. No. 125.)

Binding post 6 constitutes the common terminal for both ranges of the voltmeter. The lower range is obtained by connecting to terminals 5 and 6, and the upper range by connecting to terminals 4 and 6.

304. To Measure Insulation Resistance With The "2 In 1" Megohmer (Fig. 199), connect the resistance to be measured to the terminals marked 1 and 3. With link switch L_1 open and link switch L_2 closed, operate the generator crank until the proper voltage is developed by the generator as indicated by the voltmeter. The resistance may then be read directly from the megohm scale of the ohmmeter. The operating principle of the "2 in 1" Megohmer is explained in Sec. 74.

305. Resistances Up To 5,000 Ohms Can Be Measured With The "2 In 1" Megohmer Directly from the lower scale. Figure 200 shows the connections. Place the instru-

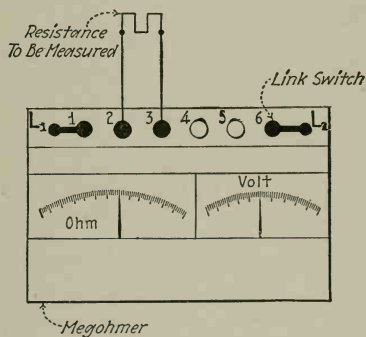


FIG. 200.—Connection of "2 in 1" megohmer for resistance measurement. (Herman H. Sticht, New York, N. Y., *Bull.* No. 125.)

ment on a firm base, so that it is approximately level. Connect resistance to be measured to the terminals marked 2 and 3. Close link switches L_1 and L_2 . Rotate the crank of the generator until the pointer comes to rest on the scale. This occurs after a few revolutions of the crank. The resistance in ohms is then read from the lower scale on the ohmmeter.

306. To Measure Insulation Resistance With A Variable-Pressure Megger Testing Set (Fig. 201), place the instrument on a firm and fairly level base. Before making any connections to the terminals of the Megger, turn the generator crank in a right-hand direction at about 100 r.p.m. At this speed the generator will develop the proper voltage. The pointer should then move over the scale and stand over the *infinity* mark. Any slight deviation from this mark can be

corrected by means of the index adjuster, so that the pointer will stand directly over the infinity mark. The "earth" and "line" terminals, *E* and *L*, should then be short-circuited by

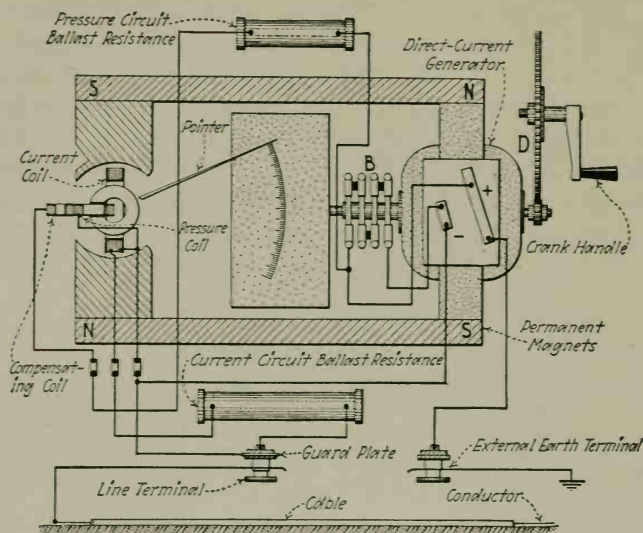


FIG. 201.—Internal connections of the "Megger" testing set shown in Fig. 192. The instrument is shown connected for measuring the insulation resistance, of a conductor in a cable. (Megger and Bridge-Megger Testing Sets, Cat. 985, James G. Biddle, 1211-13 Arch St., Philadelphia.)

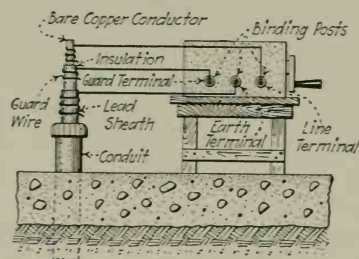


FIG. 202.—Diagram showing method of connecting for high-resistance insulation test, eliminating surface leakage by means of guard connection.

a low resistance, and the crank slowly rotated, returning the pointer to the (0) zero position of the scale. The thumb and finger can be used to short-circuit the terminals for this purpose, no unpleasant effects being felt if the crank is turned

slowly. The instrument is now ready to be connected to the circuit to be tested as shown in Figs. 202, 191 or 192. By rotating the crank at the proper speed, 100 r.p.m., the pointer will move over the scale and come to rest at a certain location on the scale which will indicate the resistance of the circuit being tested.

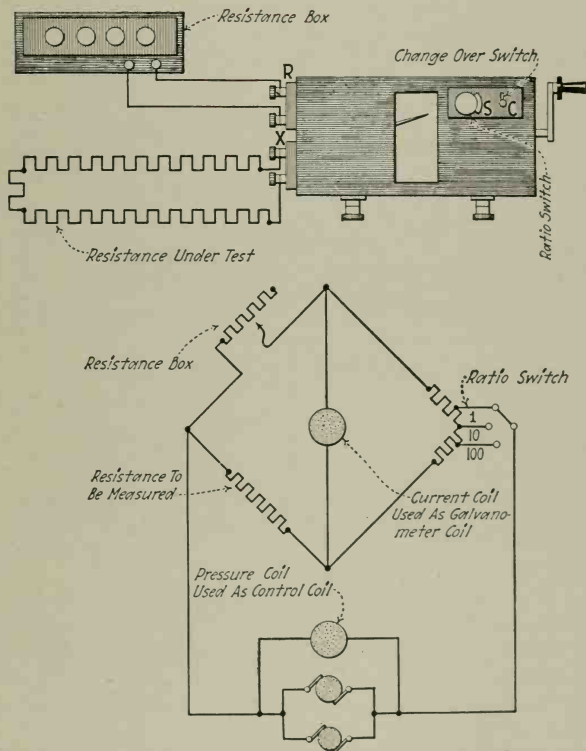


FIG. 203.—Connection diagrams for the "Bridge-Megger" Testing set for making measurements of resistances under 10,000 ohms. (Megger and Bridge-Megger Testing Sets, Cat. No. 985, James G. Biddle, Phila., Pa.)

307. NOTE.—WHEN USING THE CONSTANT-PRESSURE MEGGER TESTING SET, to measure the insulation resistance of a circuit or machine, the proper speed at which to rotate the crank is determined by increasing the speed of the crank until the clutch is felt to slip, above which speed the voltage will be constant. This occurs at about 100 r.p.m., of the crank. The procedure outlined in the preceding section is then followed.

308. The "Bridge-Megger" Testing Set Can Be Used To Measure Resistances Under 10,000 Ohms.—Figure 203-I shows the external connections for bridge measurement under 10,000 ohms, while Fig. 203-II shows the internal connections for the same measurements.

309. EXPLANATION —To make the test, set the change-over switch (C, Fig. 203) to the "Bridge" position, and the ratio, S, switch to 1. Without any connections to the terminals, turn the crank in the right-hand direction just above the slip speed. While turning the crank, set

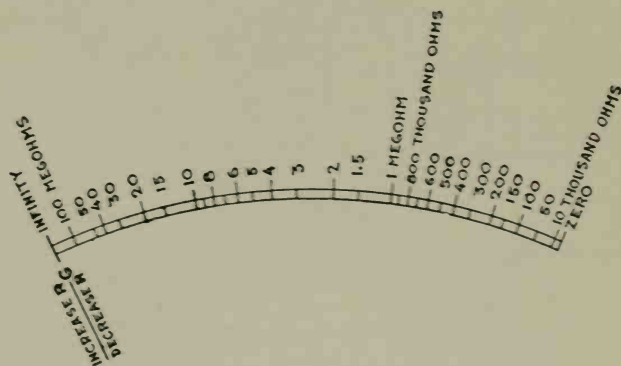
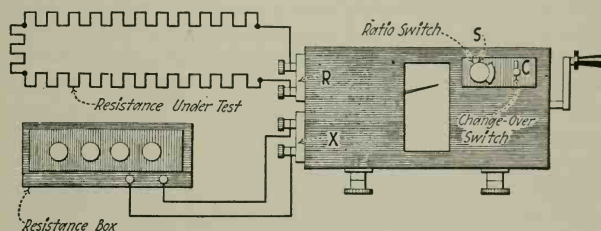


FIG. 204.—Scale of a No. 650, 0 to 100 megohm Bridge-Megger Testing Set. (*Megger and Bridge-Megger Testing Sets, Cat. No. 985, James G. Biddle, Philadelphia, Pa.*)

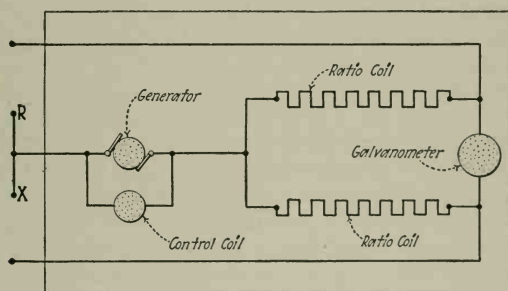
the index adjuster so that the pointer stands directly over the line G shown on the scale in Fig. 204. This is the point to which the pointer must be brought in order to indicate a balance when the instrument is used as a bridge. A resistance box and the resistance to be tested is now connected to the terminals as shown in Fig. 203-I, and the crank is slowly operated.

The resistance box is adjusted until a balance is obtained, which is indicated by the pointer taking a position directly above the G line. When the pointer moves to the position marked *increase* on the scale, resistance must be added in the resistance box, and when it moves to the *decrease* side of the scale, the resistance of the resistance box must be decreased. When a balance has been obtained, the speed of the crank should be increased to full speed, to get maximum sensibility and to insure that the final setting of the resistance box is correct. The value of the unknown resistance is equal to the resistance, in ohms, of the resistance box, divided by the value at which the ratio switch is set.

310. Bridge Measurements Of Resistances Over 10,000 Ohms Can Be Made With The "Bridge Megger" (Fig. 205-I).—The pointer is first adjusted to the *G* line as described in Sec. 309. The "Bridge Megger" resistance box is then connected to the terminals marked *X* and the resistance to be measured



I-External Connections



II-Internal Connection

FIG. 205.—Connection diagrams for the Bridge-Megger Testing Sets for making bridge measurements over 10,000 ohms. (*Megger and Bridge-Megger Testing Sets, Cat. No. 985, James G. Biddle, Phila., Pa.*)

to the terminals marked *R*, as in Fig. 205-I. When a balance is obtained, by varying the resistance of the resistance box and operating the crank, the value of the unknown resistance is determined by multiplying the resistance indicated by the resistance box by the value at which the ratio switch is set. In making this test the words "Increase *R*" and "Decrease *R*" as indicated to the left and right of the *G* line on the scale now apply in opposite sense. Thus, if the pointer deflects to the "Increase *R*" side of the *G* line, the resistance of the resistance box must be decreased.

311. NOTE.—IN USING THE “MEG” (Sec. 67) FOR TESTING THE INSULATION RESISTANCE OF CIRCUITS HAVING AN ELECTROSTATIC CAPACITY between conductors, or between conductors and ground of more than approximately 0.5 mf., it becomes difficult to drive the generator by hand at sufficiently constant speed to obtain steady readings. This is due to the slight variable pressure resulting from normal operation. Hence, for measuring the insulation resistance of high-capacitance apparatus, such as long feeder cables, telephone cables or high-power electrical machinery, where the capacity to ground is in excess of 0.5 mf., the manufacturer recommends the use of testing sets provided with constant-potential generators. Figure 69 illustrates a *Megger* which has a constant-potential motor-driven generator. This apparatus is especially suitable for the testing of circuits having capacities in excess of 0.5 mf.

312. NOTE.—IN MEASURING THE INSULATION RESISTANCE BETWEEN A CONDUCTOR AND GROUND, CARE SHOULD BE TAKEN TO OBTAIN A GOOD GROUND.—If a direct-reading resistance-measuring instrument (Secs. 302 and 306) is employed it is usually provided with two terminals. These terminals are sometimes marked “*line*” and “*earth*.” The terminal marked “*line*” should be connected to the conductor or circuit. The terminal marked “*earth*” should not be joined to some object that is merely thought to be grounded. It must be connected to a positive ground. Unless it is, the test may lead to unreliable results and give a false indication. If each piece of apparatus or conduit system is grounded, it makes no difference whether the *earth* terminal of the testing set is connected to the frame of the grounded apparatus, to the conduit system or to some other distant grounded object. However, there is always a possibility, of a distant ground connection being broken. Hence, the results of an insulation test may be misleading unless the earth terminal is connected directly to the frame of the apparatus, the sheath or the conduit of the circuit which is being tested.

313. Surface-Leakage Errors In Insulation-Resistance Measurements May Be Eliminated By The Use Of A Guard Wire (Fig. 202).—When making insulation-resistance measurements, of insulated wires or cables by the method illustrated in Fig. 202, there is a possibility of error in the results obtained due to the surface leakage, of the current, between the conductor and the outer surface of the insulator (unless the guard wire is used as there shown). This error can be eliminated, when making tests of high-insulation resistance, by wrapping a bare end of wire—a guard wire—around the insulation, between the copper conductor and the earth as shown. This wire is connected to the “guard” terminal of the instrument.

Any error which tends to occur due to surface leakage is compensated for by the guard connection. Figure 201 shows the internal connections of the guard terminal on a *megger* testing set; in Sec. 64 the principle of its operation is explained. See also the following note.

314. NOTE.—HOW A GUARD WIRE OPERATES TO PREVENT ERRORS IN INSULATION-RESISTANCE MEASUREMENTS is illustrated in Fig. 206.—In measuring the insulation resistance of the conductor to ground, a voltage is applied to the conductor and ground. The amount of current

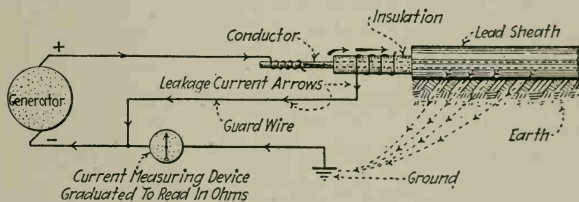


FIG. 206.—Illustrating the principle of how a guard wire prevents surface leakage from giving erroneous readings.

which flows through the insulation is indicative of its resistance. This current is measured by the current-measuring device, *M*. Therefore if some of the current creeps along the surface of the insulation and over the lead sheath and back through ground, *M* is measuring current which did not flow through the insulation. Consequently its reading is in error. But by wrapping a guard-wire, *G*, around the insulation as shown, any current which leaks over the surface of the insulation will return to the generator via the guard wire instead of via the lead sheath and ground. Note that *G* is so connected that this leakage current does not flow through *M*. Consequently it is not measured by *M*. Therefore, the only current by which *M* is affected, is that which actually flows through the insulation of the conductor.

315. To Localize The Trouble In An Electrical Circuit, When The Insulation Resistance Is Low, Separate The Various Portions Of The Circuit And Measure The Resistance Of Each Portion Separately.—For example, in an alternating-current motor circuit, disconnect the motor from the circuit, likewise the starting compensator, switches, and cutouts, then test each part of the circuit separately until the part wherein the fault is present, or where the decreased insulation resistance exists, has been located.

316. Low-Insulation Resistance On Pole-Line Circuits may be due to any of the following causes: (1) *Faulty insulators.* (2) *Tree leaks.* (3) *Accidental contact with other objects.* Each is explained in following sections. Only such faults and troubles as would not be considered strictly as *grounds* or *short-circuits*, that is only high-resistance faults, will be considered in this division. For example, an insulator which has a portion of its glazed surface chipped off (thus permitting a leakage current to pass through the insulator due to the porous portion being thus exposed to moisture absorption) may not indicate a ground on the circuit, but it would appreciably reduce the insulation resistance of the circuit. For methods of locating low-resistance grounds and short-circuits, see Div. 2.

317. High-Tension Insulators Can Be Tested For Insulation Resistance as shown in Fig. 207. A metal-lined container is

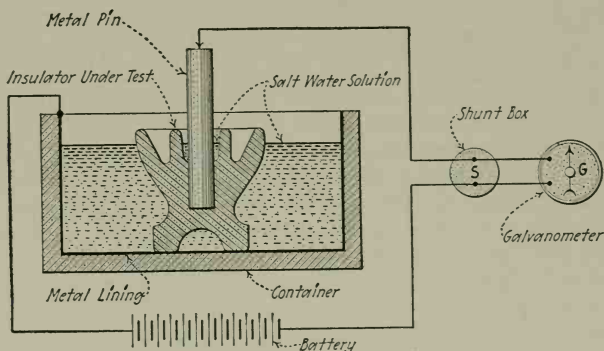


FIG. 207.—Method of measuring the insulation resistance of an insulator.

partly filled with a salt-water solution, and a portion of the solution is also poured into the insulator. A metal pin, which serves as one of the terminals for the insulation test, is inserted into the insulator. The rims of the insulator should be dry, and the test should not be made on a damp day. In making the connections for the test, one of the battery terminals is connected to the metal lining of the container. The other terminal is connected to the galvanometer *G*. The other terminal of the galvanometer is connected to the metal pin which has been inserted into the socket of the insulator. A

shunt box is connected across the galvanometer terminals. If the galvanometer shows no deflection with the shunt connected for $\frac{1}{9}$, $\frac{1}{99}$ or $\frac{1}{999}$, the insulation resistance of the insulator is considered to be sufficiently high. A Megger or similar insulation-resistance measuring instrument may also be used, following the methods hereinbefore described.

318. EXPLANATION.—The current which is forced through the insulator (Fig. 207) will divide through the shunt box and the galvanometer in inverse proportion to the ratio of their respective resistance. That is, if the resistance of the shunt box is increased a larger proportion of the current will go through the galvanometer. The lowest resistance of the shunt box is obtained when connected for " $\frac{1}{9}$." The next highest is " $\frac{1}{99}$," and the highest is " $\frac{1}{999}$." Consequently, when testing an insulator by this method the first test should be made on the " $\frac{1}{9}$," the second on the " $\frac{1}{99}$," and the third test on the " $\frac{1}{999}$." The reason for this is that if the insulator should be defective, the " $\frac{1}{9}$ " or the " $\frac{1}{99}$ " connection on the resistance box will permit the large current to flow through the box instead of through the galvanometer, thus preventing the burning out of the galvanometer.

319. NOTE.—THE GALVANOMETER METHOD OF INSULATION-RESISTANCE MEASURING (Fig. 207) is practical only for laboratory testing. It could not be used in the field.

320. NOTE.—INSULATORS WHICH ARE INTENDED FOR HIGH-POTENTIAL SERVICE should also be tested for their ability to withstand high potentials. The resistance of an insulator may be quite different when subjected to a high potential than when tested with a relatively low voltage. When high-potential insulators are tested at the factory, they are usually subjected to a difference of potential several times greater than that which they are intended to withstand in use.

321. Defective Insulators May Be Caused By Cracks In The Porcelain Which Reduce Their Insulation Resistance.—Several methods of detecting defective insulators are used. These methods may be classified as follows: (1) *Locating defective insulators on transmission lines while the line is in operation.* (2) *Locating defective insulators on transmission lines when the line is dead.* It is obvious that the former method would be the most desirable since periodic tests will often reveal a defective insulator. Then it can be replaced before a breakdown occurs. Both of the above methods for locating defective insulators are explained in the following sections.

322. Defective Insulators On Pole Lines May Be Located By The "Buzz Stick."—This method can be used for locating defective insulators of either the suspension or the multiple-part pin type. It was invented and patented by T. F. JOHNSON, JR., ATLANTA, GEORGIA. The tools used in this method

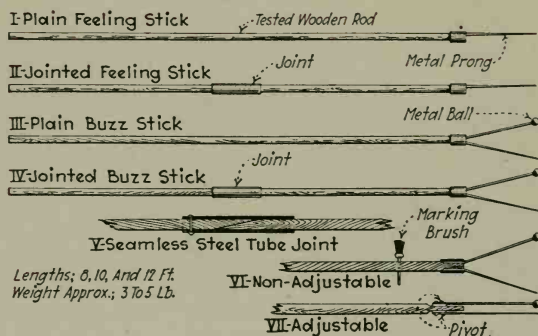


FIG. 208.—Diagram showing tools used for testing in locating defective insulators by the Buzz-Stick method. (T. F. Johnson, Jr., Atlanta, Georgia.)

of insulator testing are shown in Fig. 208. An explanation of the buzz-stick method of testing for defective insulators is given in the following sections.

323. There Are Two Steps In The Buzz-Stick Method Of Testing For Defective Suspension Insulators.—The first step is the *feeling-out* test and the second step is the *shorting-out* test. The feeling-out operation which determines the general condition of the string of insulators under test, always precedes the shorting-out operation. Although the feeling-out operation does not definitely determine the exact condition of the string of insulators it does give a fair indication of their condition, and shows whether or not the shorting-out operation can be applied without the danger of flashing over or puncturing the string of insulators. The shorting-out operation always follows the feeling-out operation, except where the feeling-out of the string of insulators has indicated that it would be dangerous to apply it. The shorting-out operation accurately locates the defective unit.

324. To "Feel-Out" A String Of Suspension Insulators By The Buzz-Stick Method, (Fig. 209) touch the ball of the

buzz stick to the line conductor and draw it slowly away. This produces a distinct buzzing sound which in the case of 110,000 volts, continues to be audible until the ball is some 2 or 3 in. away. Repeat this operation on the cap of each successive insulator. It will be found that the sound is less for each cap as the distance from the line conductor increases, until cap No. 5 or No. 6 (Fig. 209) is reached. At this location there is little or no sound, and the sound from cap No. 7 is louder than from caps No. 5 or No. 6. These conditions indicate a perfectly good string.

The intensity of the spark is judged by the sound, not by its length. If insulator No. 2 is totally bad the sounds from caps No. 1 and No. 2 will be equal. If insulator No. 5 is bad, caps No. 4 and No. 5 will produce equal sounds and the sound from cap No. 6 will be very much increased. If insulators Nos. 2, 3, and 4 are

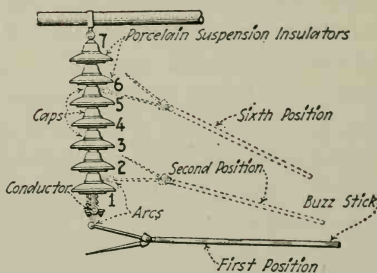


FIG. 209.—Illustrating the first step or the feeling-out process of the Buzz-Stick method of locating defective units in a string of suspension-type insulators. (T. F. Johnson Jr., Atlanta, Ga.)

defective, then the sounds from caps Nos. 5, 6, and 7 will be very much increased. From the above it can be said that the volume or intensity of the sound from the cap of a dead insulator is the same as that from the cap of the next insulator to it nearest to the line.

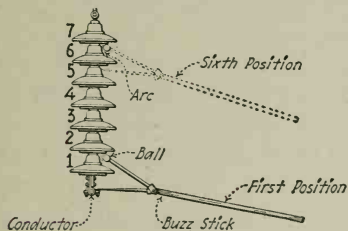


FIG. 210.—Illustrating the second step or the "shorting-out" process of the Buzz-Stick method of locating defective units in a string of suspension-type insulators. (T. F. Johnson Jr., Atlanta, Ga.)

325. The Shorting-Out Process Of Locating Defective Insulators By The

Buzz-Stick Method (Fig. 210) is performed as follows: Touch the prong of the buzz stick, on which there is no ball, to the line conductor. Then, while holding this prong in contact

with the line, make and break the contact between the buzz ball on the other prong and cap No. 1. There will be produced a snappy spark on making and breaking contact with cap No. 1. This constitutes the shorting-out test of insulator No. 1. To short-out insulator No. 2, hold the prong, on which there is no ball, in contact with cap No. 1, and make and break contact between the other prong and cap No. 2. A snappy spark will be produced on making and breaking contact with cap No. 2, but the intensity of the spark will be less than when the horn was held in contact with the line conductor, and the ball touched to cap No. 1. By repeating this operation across each insulator unit in the string, it will be found that the intensity of the spark will be more intense than across unit No. 6. These conditions indicate a perfectly good string of insulators. If, say unit No. 2 is dead, there will be absolutely no spark when this unit is shorted out.

326. NOTE.—THE NUMBER OF GOOD INSULATOR UNITS WHICH IS REQUIRED IN A STRING TO STAND THE LINE POTENTIAL WHEN THE SHORTING-OUT PROCESS IS BEING APPLIED DEPENDS UPON THE POTENTIAL OF THE SYSTEM UNDER TEST.—Roughly, on 110,000-volt lines there must be at least three good units left in the string to withstand the *shorting-out* process. On lower voltages there must be at least two good units, except on voltages of 11,000 and 13,000 where there are only two insulator units per string, then only one unit need be good.

327. The Insulator, Of A String Of Good Insulators, The Cap Of Which Gives The Minimum Spark, When Applying The Feeling-Out Process, Is Called The Silent Insulator.—It is not as its name implies always absolutely silent. Whether it is or not depends on its construction. However, in every string of insulators of the proper length and number for the voltage of the line upon which they are used, there is one insulator, the cap of which will, during the feeling-out process, give a less intense spark than any other insulator. Where the string is too long for the voltage applied, there will be more than one silent insulator. The number of such silent insulators will depend upon the amount of overinsulation of the line. When the number of insulators per string are too few for the voltage of the line, there will be no truly silent insulator.

328. The Buzz-Stick Method For Locating Defective Pin-Type Insulators Is Applicable Only To Multiple-Part Insulators When The Various Parts Are Cemented Together And Where This Cement Is Accessible With The Testing Tools.—The tools used in applying this method are of two types, as illustrated in Fig. 208-I and -III. The instrument which is

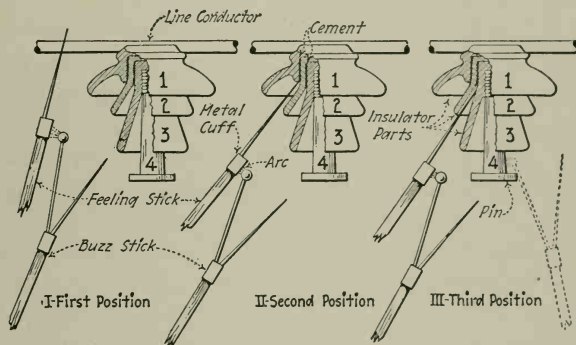


FIG. 211.—Diagram showing the progressive positions of the first step or feeling-out process of the Buzz-Stick method of locating a defective part of a pin-type multiple-part insulator. (T. F. Johnson, Jr., Atlanta, Ga.)

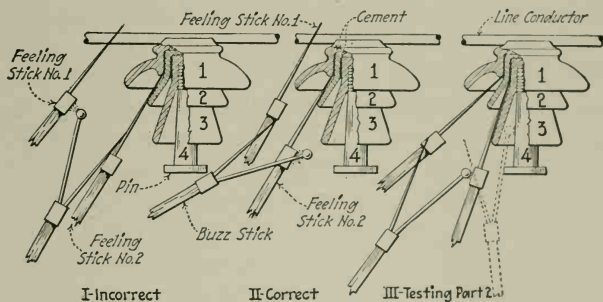


FIG. 212.—Diagram showing the progressive positions of the second step or shorting-out process of the Buzz-Stick method of locating a defective part of a multiple-part, pin-type insulator. (T. F. Johnson, Jr., Atlanta, Ga.)

shown in Fig. 208-I is called a *feeling stick*. Where the insulators under test have more than two parts (Figs. 211 and 212), two feeling sticks are required. Where the insulators consist of only two parts (Fig. 213), only one stick of this kind is

necessary. Figure 208-III illustrates a *shorting stick*. Only one shorting-stick is required in testing, regardless of the number of parts constituting the insulator.

329. To Feel Out A Multiple-Part Pin-Type Insulator (Fig. 211), touch the feeling point of the feeling stick, (Fig.

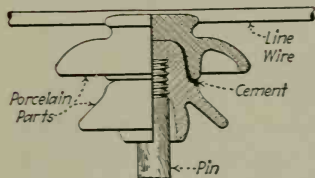


FIG. 213.—Diagram of a two-part pin-type insulator.

208-I) to the line conductor, and while maintaining this contact touch the ball end of the buzz stick (Fig. 208-III) to the metal cuff on the end of the feeling stick and draw it slowly away from the cuff. A distinct buzzing sound will be produced, which in the case of a 60,000-volt line will be audible

until the ball is an inch or more away. This operation is repeated with the point of the feeling stick resting firmly on the cement between parts No. 1 and No. 2 (Fig. 211-II). If the porcelain part No. 1 is in good condition, the intensity of the sound will be less when the ball of the buzz stick is drawn away from the cuff of the feeling stick in this case than when the feeling stick was in contact with the line conductor. If part No. 1 is defective, the sounds produced in the two cases will be about the same; the more defective the insulator part the more nearly will the sound produced duplicate that which was emitted when the feeler was held in contact with the line. This operation is repeated until each porcelain part has been tested. The greater the difference in the sound given off when the feeler contacts with the cement on either side of the part being tested, the nearer perfect is the porcelain part. When the last part is reached the feeling operation is made on the cement on one side of the porcelain part and on the pin on the other side (Fig. 211-III).

330. NOTE.—THE INTENSITY OF SOUND MAY BE DECEPTIVE.—From the preceding section it is natural to conclude that when porcelain part No. 1 is totally defective, the sound from the line and the sound from the cement between parts No. 1 and No. 2 will become equal. This conclusion is seldom verified by what actually happens on the line. The sounds approach near enough to equality, under almost any conditions, to excite suspicion about part No. 1. On the other hand it is very exceptional that they become equal.

331. NOTE.—THE SHORTING-OUT PROCESS, OF THE BUZZ-STICK METHOD FOR LOCATING DEFECTIVE PARTS OF A MULTIPLE-PART PIN-TYPE INSULATOR, SHOULD BE PRECEDED BY THE FEELING-OUT PROCESS.—This precaution must be taken to prevent flash-overs while the shorting-out process is being applied. Should the shorting-out test (described below) be applied to a good part of an insulator which has some defective parts, a flash-over is likely to result and put the line out of service. The feeling-out step will indicate such defective parts and serve as a guide in the shorting-out step.

332. To Short-Out A Multiple-Part Pin-Type Insulator (Fig. 212-*II* and *III*) proceed as follows: Place the point of a feeling stick (No. 1) against the line. Place the feeling point of a second feeling stick firmly against the cement between insulator parts No. 1 and No. 2. With the pointed prong of the buzz stick (Fig. 212-*II*) against the cuff of feeling stick No. 1, make and break contact between the cuff on the feeling stick No. 2 and the ball on the other fork of the buzz stick. A snappy-sounding spark will be produced if the upper part of the insulator is in perfect condition. If the part under test is defective the sound of the spark will be less than the normal spark of a perfect part. The degree of defectiveness will determine the intensity of the sound of the spark when this test is applied. However, there is practically always some spark, even with a totally defective part. To short-out insulator part No. 2, proceed in a manner similar to that which is outlined above and as illustrated in Fig. 211-*III*. The process is continued until each part of the insulator has been tested. When the last part is to be tested, where a metal pin is used, the shorting is done between a feeling point resting on the cement which is between the last two parts and the pin which supports the insulator, as shown in dotted lines in Fig. 211-*III*. Where wood pins are used, a feeling point is forced as far as possible up inside the insulator next to the wood pin and the shorting done between this point and a feeling point on the cement which lies between the last two parts.

333. NOTE.—THE BALL OF THE SHORTING STICK OR BUZZ STICK SHOULD ALWAYS BE AWAY FROM THE LINE CONDUCTOR DURING THE SHORTING-OUT PROCESS. Figure 212-*I* shows the incorrect method of using the shorting stick, while Figs. 212-*II* and *III*, show the correct method.

334. Multiple-Part Pin-Type Insulators Can Be Tested To Locate Defective Parts By The Use Of The "Pin-Insulator Buzz Stick" (Fig. 214).—The progressive steps in testing a three-part pin-type insulator are diagrammed in Fig. 215.

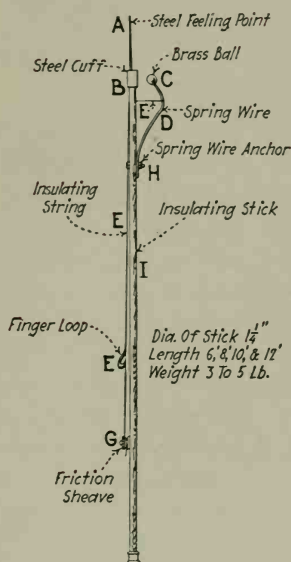


FIG. 214.—Diagram of pin-insulator buzz stick. (T. F. Johnson, Jr., Atlanta, Georgia.)

Step 1, (Fig. 214-I) consists in placing the steel point A of the buzz stick against the line conductor, then turning sheave G to decrease the distance between B and C. The intensity of the spark can be better judged by its sound than by sight. Step 2 consists in placing the steel point A (Fig. 215-II) against the cement between part No. 1 and part No. 2, then placing the finger in the finger loop F (which is attached to the insulating string E) and pulling it gradually until the distance between B and C is decreased sufficiently to re-establish a continuous spark between B and C. Step 3 (Fig. 215-III) consists of a repetition of step 2 with the feeling point A touching the cement between parts No. 2 and No. 3. If the distance

between B and C decreases in direct-proportion for each of the successive steps, the test indicates a good insulator. A spark of the same intensity on either side of a part, with the sparking distance B and C remaining the same, would indicate a defective part. Step 4 consists in drawing a spark from the steel pin, which supports the insulator, with the ball of the buzz stick drawn against the steel cuff, B, while the feeling point of the buzz stick touches the cement between parts No. 2 and No. 3. If no spark is drawn between the head of the buzz stick and the pin, part 3 would be totally defective.

335. NOTE.—STEP NO. 4 SHOULD NOT BE APPLIED IF PARTS NO. 1 AND NO. 2 ARE NOT IN PERFECT CONDITION (Fig. 215).—It is therefore obvious that parts No. 1 and No. 2 must be tested and found to be

perfect before part No. 3 is shorted out. Otherwise, a flash over is likely to occur and put the line out of service.

336. NOTE.—THE BUZZ-STICK METHOD WILL NOT INDICATE CRACKS ON THE OUTER EDGES OF THE PORCELAIN PARTS OF AN INSULATOR, nor will it indicate broken insulators. However, it will indicate all defects when they extend into the main body of the insulator, such as cracks, holes, porosity and other defects in the porcelain.

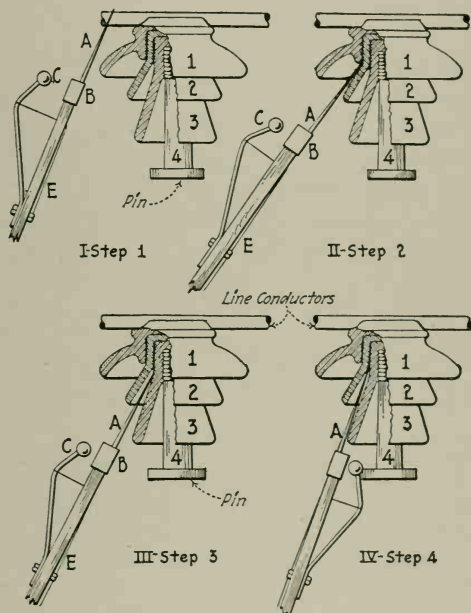


FIG. 215.—Progressive steps in the process of testing multiple-part pin-type insulators using the pin-insulator buzz stick.

337. In The Hands Of A Novice There Are Certain Dangers Accompanying The Buzz-Stick Method Of Testing For Defective Insulators.—They are due to the likelihood of the inexperienced tester flashing a string of insulators and putting the line out of service. To avoid these dangers the tester should test the lowest string of insulators on the tower first, and should stand well below the string he is testing. When a wind is blowing, he should stand with the wind blowing from him to the string. He should protect his eyes with colored glasses. If these precautions are taken, any arc, which might

accidentally be started, will always travel away from the tester, and there will be no danger to him, whereas there would be if he stood under a string of insulators which was about to fall.

338. Defective Insulators Can Be Located By Measuring Their Insulation Resistance With A Megger.—Figure 216 shows a megger fork which can be easily constructed and which

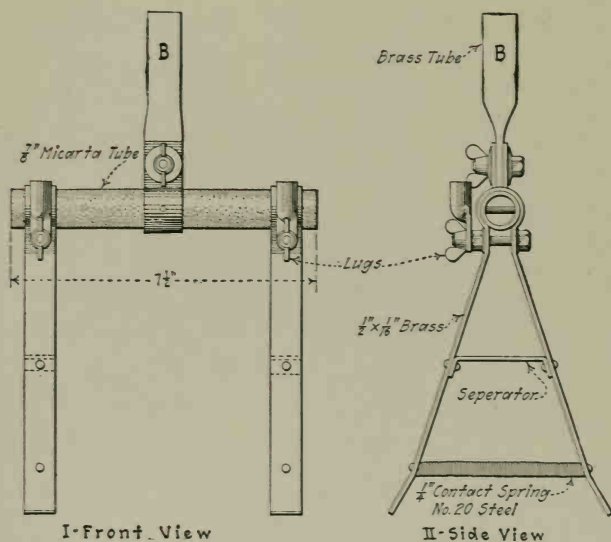


FIG. 216.—Megger fork which facilitates testing line insulators.

facilitates testing suspension-type line insulators. (This arrangement can be used only when the line is dead.) Such a device often receives rough handling in the field, even being dropped from the top of towers. Therefore it must be practically unbreakable.

339. DESCRIPTION.—The fork support (Fig. 216) consists of a $\frac{3}{8} \times \frac{1}{16}$ -in. micarta tube about $7\frac{1}{2}$ in. long, near the ends of which are fastened forks of $\frac{1}{2} \times \frac{1}{16}$ -in. brass clamped on the micarta tube and spaced apart by a flat brass separator. Between the ends of each fork is attached a contact spring $\frac{1}{4}$ in. in diameter and 4 in. long. At the center of the micarta tube, a brass tube (B) is attached by means of an adjustable joint, into which a ferrule on the end of a bamboo pole may be inserted. The bamboo pole may be made up into 5-ft. sections for easy carrying. By means of the adjustable joint, which is provided with a wing nut, the fork may be turned to any desired angle for testing. When

in use, one of the springs rests on the cap of the insulator, and the other rests on the stud.

Its application to the insulators is very easy as the springs do not require that the fork be held steadily in one place. Lead wires for connection to the megger are inserted into the lugs attached to the forks. The lead wires consist of heavy lamp cord, having the cloth covering skinned back about 2 in. from the end of the wire, thus leaving the rubber insulation exposed. This is to prevent leakage currents from creeping over the cloth insulation on the wire.

340. The Insulation Resistance Of A Pole Line May Be Decreased By Tree Leaks.—Tree branches and foliage coming in contact with conductors provide a path for leakage currents to flow to the ground thus reducing the insulation resistance of the circuit. Tree leaks can frequently be located by patrolling the line and hunting for a tree or some other object which is contacting with the conductor. A method of locating a tree leak is described in the following sections.

341. Tree Leaks May Be Located With The Lundin Fault Locator (Fig. 51 Div. 1).—That the fault on the line is caused by a tree leak is ascertained by the analyzer (Sec. 51). To locate the tree leak, the circuit on which the fault occurs is energized by an interrupted current produced by the device. The circuit is then patrolled, by the troublemen, using an exploring coil as shown in Fig. 217. When the exploring coil is placed alongside of the tree which is causing the leak, a distinct buzz will be obtained in the telephone receivers which are connected to the coil. The buzz in the telephone receivers being caused by a leakage current flowing down the tree, indicates that the fault is likely caused by that tree.



FIG. 217.—The triangular coil used to locate tree leaks. (Manufactured by The Lundin Electric and Machine Co., Boston, Mass.)

QUESTIONS ON DIVISION 5

1. How can the general condition of an electric circuit be determined?
2. Why should insulation resistance be measured periodically? How often should such periodic measurements be made?
3. How may the properties of insulation be classified?
4. What effect does a prolonged high voltage have upon the dielectric strength of insulating material?
5. How does insulation resistance vary with changes in temperature?
6. What is likely to occur if the insulation of an electric circuit is subjected to an extremely high temperature?
7. What two things frequently cause low insulation resistance?
8. What is meant by "green" insulation?
9. Why should insulation-resistance measurements be made from time to time during the process of drying out a machine?
10. What is the formula for determining the minimum permissible insulation resistance of a machine in accordance with the A. I. E. E. specification? Illustrate by an example.
11. What are the requirements of the "National Electrical Code" regarding the insulation resistance of an interior-wiring installation?
12. Explain, with a diagram, a method for determining the insulation resistance of a rubber-covered conductor.
13. What are the units in which the insulation resistance of a cable are generally expressed?
14. What is meant by "the insulation resistance of each conductor" of a multi-conductor cable?
15. Explain how the approximate insulation resistance of a circuit may be determined with a magneto.
16. Why is the magneto method not applicable for determining the insulation resistance of long lines?
17. Explain by a diagram how to determine insulation resistance with a voltmeter.
18. Give the formula for the voltmeter method and illustrate with an example.
19. What is the function of the lamp in the voltmeter method?
20. What is the most convenient and quickest method of determining insulation resistance?
21. Make a diagram of connections and explain how to measure insulation resistance with a Model "D" Megohmer.
22. Make a diagram of connections for measuring voltage with the Model "D" Megohmer.
23. Make a diagram of connections for measuring insulation resistance with the "2 in 1" Megohmer.
24. Make a diagram of connections and explain how to measure insulation resistance with the Megger.
25. Why should a positive ground be used when measuring the insulation resistance between a conductor and ground?

26. How may surface leakage errors be prevented?
27. How may a point of low insulation resistance on a circuit be localized?
28. What are some of the causes of low insulation resistance to ground on a pole line?
29. How may insulators be tested for insulation resistance when not on the line?
30. What may be the cause of defective insulators?
31. Describe the buzz-stick method for locating defective insulators of the suspension-type insulators. Illustrate.
32. What precaution must be taken in applying the shorting-out step in the buzz-stick method for locating defective parts of a suspension-type insulator?
33. What are the minimum number of good parts that should be available in a string of suspension-type insulators for various voltages, to safely apply the shorting out process?
34. Describe the buzz-stick method for locating defective parts of a multiple-part pin-type insulator.
35. Describe the method for locating defective parts of a suspension-type insulator by the Megger method, using a fork.
36. How can tree leaks be located on an overhead pole line, using the Lundin Fault Locater?

DIVISION 6

DETERMINING POLARITY

342. The Polarity Of An Electrical Conductor is the term which relates to the direction of current flow in the conductor. This polarity of a conductor should not be confused with *magnetic polarity* which is quite another thing. The *positive (+) conductor* is the one from which the *electric current* flows or tends to flow due to the direction and force of the applied voltage. The *negative (-) conductor* is the one into which the electric current flows or tends to flow, due to the direction and force of the applied voltage. For a further discussion on polarity see author's "Practical Electricity."

343. The Reason For Having To Determine Polarity is that many electrical devices will function rightly only if they

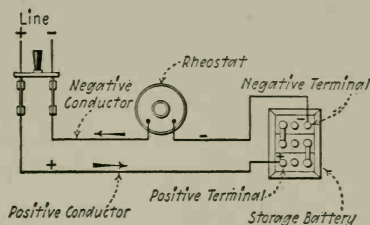


FIG. 218.—Diagram showing the connection of a storage battery to a charging circuit. The *positive (+)* battery terminal is connected to the *positive (+)* line terminal and the *negative (-)* battery terminal is connected to the *negative (-)* line terminal. A rheostat is connected in series with the battery to limit the current-charging rate.

are connected properly as to polarity. That is, the "positive" (+) conductor of the circuit should be joined to the "positive" binding post of the device, and the "negative" (-) conductor to the "negative" binding post. This relates particularly to direct-current devices. No attempt will be made here to discuss alternating-current polarities. The following examples indicate some of the services in which proper connection, as to polarity, is essential.

344. EXAMPLE.—STORAGE BATTERIES (Fig. 218) can be charged with direct current only. Furthermore the *positive* (+) terminal of the charging circuit must be connected to the *positive* (+) terminal of the battery, and the *negative* (−) terminal of the charging circuit must be connected to the *negative* (−) terminal of the storage battery. Figure 218 shows the correct method of connection for a storage battery to a charging circuit.

345. EXAMPLE.—DIRECT-CURRENT ARC-LAMPS (Figs. 219 and 220) should be correctly connected as to *polarity*. When an arc is maintained across the gap, the carbons are consumed, and a cup-shaped depression, termed the crater, is formed in the *positive* (+) carbon, while the tip of the *negative* (−) carbon assumes a conical form. The *positive* (+) carbon should be the upper carbon, and the *negative* (−) carbon the lower carbon. This arrangement of carbons (Fig. 219) causes the light to be thrown downward, the crater in the upper or *positive* (+) carbon directs the rays of light downward.

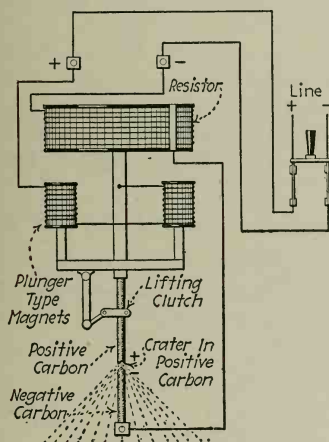


FIG. 219.

FIG. 219.—Diagram showing correct polarity of carbons in a direct-current arc lamp. The upper carbon is connected to the *positive* (+) terminal and the lower carbon to the *negative* (−) terminal of the circuit.

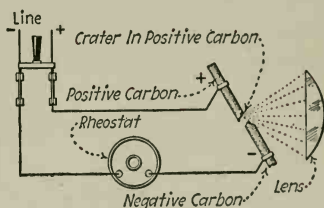


FIG. 220.

FIG. 220.—Diagram showing correct polarity of carbons used in motion-picture projection machines. It is very important to have the carbons set properly in this application of the electric arc light.

Figure 220 shows the correct polarity for the carbons used in a motion-picture machine.

346. EXAMPLE.—ELECTROPLATING VATS (Fig. 221) require strict observance as to polarity of their electrodes. The *positive* (+) plate or electrode, is called the *anode*, and the *negative* (−) plate or electrode is called the *cathode*. Figure 221 shows an electroplating circuit with *polarity* markings.

347. EXAMPLE.—TO OBTAIN MAXIMUM SERVICE FROM THE CONTACTORS ON CIRCUIT-BREAKERS, MAGNETIC SWITCHES, AND OTHER CIRCUIT-MAKING AND CIRCUIT-BREAKING DEVICES, which have carbon to copper contactors, the *polarity* of the contacts should be observed. That is, the

carbon contactor should be made the *positive* (+) terminal and the copper contactor, the *negative* (−) terminal. This causes the carbon contactor to be consumed by the arc formed when opening the circuit by means of the device. The carbon contactors are usually made removable, so that they may be readily replaced.

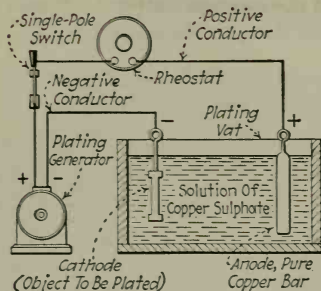


FIG. 221.—Copper electro-plating circuit, showing correct polarity.

348. EXAMPLE.—MAGNETIC BLOW-OUT COILS (Fig. 222) on direct-current circuit-breakers and large controllers, should be connected correctly with reference to polarity. The relative directions of the magnetic field produced by the blow-out coils and that produced by the arc, which occurs upon breaking a circuit while the circuit is carrying a current (Fig. 222), should be such that the arc is forced away from the contacts and the device.

349. The Methods Of Determining The Polarity Of A Direct-Current Circuit May Be Classified As Follows: (1) *Electro-chemical-action* (Secs. 350 to 358). (2) *Electro-magnetic*

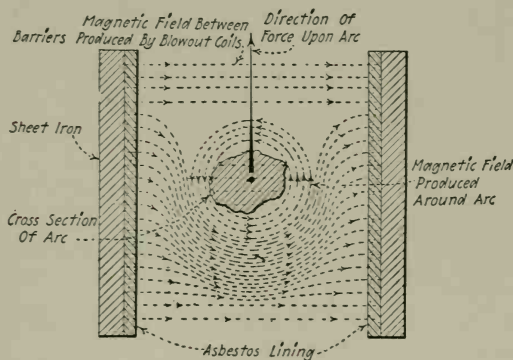


FIG. 222.—Diagram showing the principle of the magnetic blow-out as applied to circuit breakers. (There is always a force on any current-carrying conductor—in this case the arc is the current-carrying conductor—which lies in a magnetic field, tending to thrust the conductor from the field in a direction at right angles to the direction of the field.)

(Secs. 359 to 368).—They are explained thus: *In the electro-chemical action method*, the polarity is determined by noting the effects produced by passing a current through some con-

ducting substance, usually a liquid, which will react chemically to an electric current. *In the electro-magnetic method*, the polarity of the terminals of a circuit is determined by ascertaining the direction of the *magnetic field* around the conductor while a current is passing through it. This is accomplished by means of a *compass* or some similar device. Both of these methods are described in following sections.

350. The Electro-Chemical-Action Method Of Determining Polarity Depend Upon Electrolysis.—Electrolysis is the chemical decomposition of an electrolyte which is caused by the flow

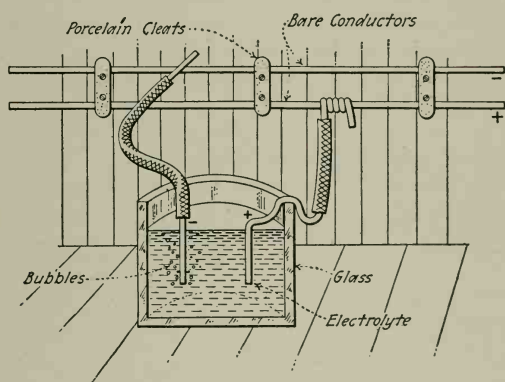


FIG. 223.—One of the simplest forms of polarity tester.

of an electric current through it. The most common application of electrolysis, in the determination of polarity, is effected by passing a current through an electrolyte and observing the terminal around which the greater number of bubbles are produced. This is the negative wire of the circuit. Another common method, of determining polarity is by noting the difference in color around one of the terminals when it is dipped into an electrolyte of a certain chemical composition. Several applications of the above methods of determining polarity are outlined in the following paragraphs.

351. EXAMPLE.—PROBABLY THE MOST FREQUENTLY USED POLARITY TEST is that shown in Fig. 223. If two terminals of a direct-current circuit be submerged in a conducting liquid, bubbles will form on the negative electrode. No bubbles (or at least very few) will form on the

positive. Thus, the arrangement in Fig. 223 will provide not only a polarity indicator but a voltage detector, because, unless a certain voltage is impressed across the two submerged electrodes no bubbles will form. The liquid used is salt or acid water. Pure water is, contrary to the idea usually accepted, such a poor conductor that it is almost an insulator. Hence, to render the water conducting, common table salt or some acid should be added to it. If salt is used, one-half tablespoonful will ordinarily be sufficient for a tumblerful of water. If acid is used, 10 or 12 drops for a tumblerful of water will probably be sufficient. See following section for permissible voltages. The containing vessel must be of an insulating material, either glass or earthenware. A metallic vessel is liable to short-circuit the electrode ends. Clear glass is best because through it one can readily observe the bubbles as they form on the electrode end. The submerged electrode ends should not touch each other. If many tests for polarity are to be made, a more permanent device than that shown in Fig. 223 will be convenient.

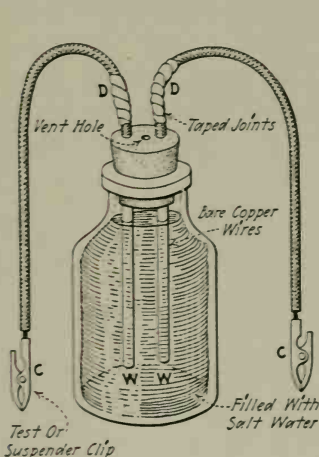


FIG. 224.—"Bottle tester" for low battery voltages.

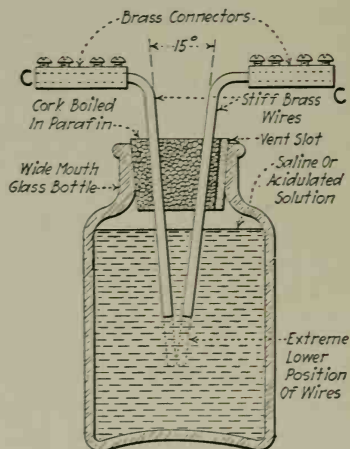


FIG. 225.—Polarity tester for testing circuits of different voltages.

352. EXAMPLE.—AN ELECTROLYTIC POLARITY TESTER FOR LOW-BATTERY VOLTAGES is shown in Fig. 224. Electrodes W and W are pieces of brass or copper wire inserted in the cork. The cork should be boiled in paraffine to improve its insulating properties. A vent hole should be burned through it to permit the gases generated by electrochemical action to escape, otherwise the cork may be blown out of the bottle. Each electrode should have soldered to it a flexible-cord lead. On the free end of each lead a test clip C and C should be soldered. Suspender clips can be used or the commercial test clips regularly manufactured for such service can be employed. A wrapping of tape should be

served neatly around the junction at *D*. The bottle is filled within about 1 in. of the cork. When this polarity indicator is used on 110 or 220-volt circuits it is necessary to insert in series with it a resistor to limit the current and thus prevent disastrous short-circuit accidents. Incandescent lamps are usually most convenient.

Where the same polarity indicator must be used for testing successively a number of circuits of different voltages the construction shown in Fig. 225 is convenient. The electrodes are not arranged vertically through the cork as in Fig. 224, but are at an angle of about 15 degrees to each other. When a circuit of relatively high voltage is under test, the electrodes can be partially withdrawn from the bottle so that the distance between the ends in the bottle is correspondingly great. For testing a very low-voltage battery circuit, the electrodes would be pushed farther into the bottle and until the ends are close together. Stiff brass wire should be used because copper, unless of excessively large diameter, is liable to bend when pushed into the cork. A vent *V* is cut in the side of the cork. Brass connectors *C* and *C'* afford a convenient means of connecting the indicator to the circuit.

353. EXAMPLE.—A CONVENIENT FORM OF ELECTROLYTIC POLARITY INDICATOR WITH LAMP RESISTANCE is shown in Fig. 226. The base may be about a foot square, $\frac{7}{8}$ in. thick and should be shellacked. A porcelain lamp receptacle *L* is fastened to the base; also binding posts, *B* and *B'*, are connected to the lead wires from the circuit under test. A clear glass tumbler *G* contains the electrolyte. Where the electrodes *F* and *F'* are firmly supported in holes bored in the base, it is often convenient to make them of fuse wire. Fuse wire electrodes are not suitable for indicators like those of Figs. 224 and 225, because they yield too readily.

354. NOTE.—THE REASON FUSE WIRE IS DESIRABLE (fuse wire is composed largely of lead) under certain conditions is that, after current has passed through it for a short time, the positive electrode will assume a brown color while the negative electrode will become gray. These color deposits constitute a record of the polarities. When an indicator must be used where the connection of the test wires to the circuit is not visible, the tester can hold the leads in contact with the circuit for a short time and then return to the indicator and be able to determine which is the positive and which the negative by noting the colors on the electrodes.

355. EXAMPLE.—A MAKESHIFT POLARITY INDICATOR can be very quickly made from a perfect or a burnt-out incandescent lamp, as in Fig. 227. First prepare a salt or acid electrolyte in a vessel about 10 inches in diameter, then submerge the tip of the lamp in the electrolyte

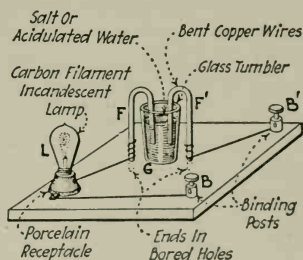


FIG. 226.—A permanently mounted polarity indicator.

and "bite" it off with a pair of cutting pliers. The electrolyte will rise and fill the vacuum space in the glass bulb. A lamp receptacle *R* may be attached to a suitable wooden base block. Insert a piece of small wire with a hook bent on its lower end through the hole in the upper end of the bulb and break off the filament leaving the two copper ends *W* and *W* extending as shown. Then the indicator will be complete.

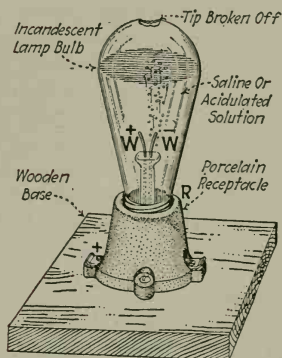


FIG. 227.—Polarity indicator made from a discarded incandescent lamp.

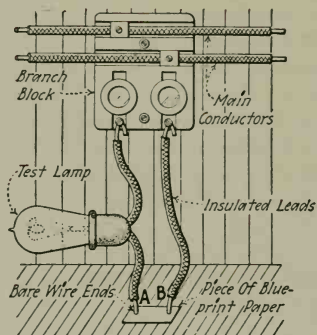


FIG. 228.—Using blueprint paper for finding polarity.

356. EXAMPLE.—A SPLENDID METHOD OF DETERMINING POLARITY WITH BLUE-PRINT PAPER, which has been exposed and washed, is suggested on Fig. 228. This scheme is often utilized by wiremen on construction jobs, where remnants of old blue-prints are always at hand. A piece of the paper about 1 in. square is moistened with water or saliva. Then the ends of the two test wires *A* and *B* are held down against it about $\frac{1}{4}$ or $\frac{3}{8}$ in. apart. Around the negative lead the paper will turn white, while around the positive it will not be appreciably changed in color. A lamp resistor should always be used in series with one of the test wires, as shown, to eliminate the possibility of accidents due to short-circuits.

357. EXAMPLE.—A POLARITY INDICATOR IS SOMETIMES CONSTRUCTED BY SEALING A SOLUTION OF IODIDE OF POTASSIUM, TO WHICH A LITTLE STARCH HAS BEEN ADDED, into a glass tube provided with suitable terminals. When a current is passed through the solution, iodine is liberated at the positive terminal, which turns the starch blue around the terminal. There are other chemical solutions which give different colors at one or the other of the terminals. Figure 229 shows the form of a commercial polarity indicator, manufactured by the Manhattan Electric Supply Co., New York City and St. Louis, Mo., now in general use. The liquid turns red at the negative terminal of this indicator, the price of this instrument, both sizes, is about \$2. It operates very

satisfactorily. It is manufactured in two sizes; one is for battery voltages, up to 30 volts; the other is for 30 to 600 volts.

358. EXAMPLE.—A PIECE OF POTATO MAY BE USED IN DETERMINING THE POLARITY of a circuit. Touch a piece of potato with the bared ends of conductors connected to the circuit the polarity of which is desired. The negative terminal will discolor the portions of the potato surrounding it. The conductor ends must be placed on the white "meat" of the potato—not on the skin.

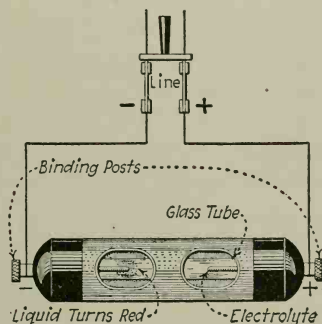


FIG. 229.—A convenient form of polarity tester which indicates the negative terminal of a direct-current circuit by discoloring the solution at the negative terminal when a current is passed through the solution. (Manufactured by the *Manhattan Electric Supply Co.*, St. Louis, Mo.)

359. The Electro-Magnetic Method Of Determining The Polarity Of A Conductor Consists In Ascertaining The Direction Of The Magnetic Field Around The Conductor When A Current Flows Through It.—When an electric current flows through a conductor a magnetic field is set up around the conductor, and the direction of this magnetic field depends upon the direction of the flow of current through the conductor. From the foregoing, it is evident that by knowing the direction of the magnetic field about the conductor, the polarity of the conductor can be determined. Examples of the above method for determining polarity are given in the following sections.

360. The Compass Method Of Determining The Polarity Of A Conductor (Fig. 230), when the conductor is carrying direct current, consists in placing a compass above or below the conductor, and noting the direction in which the *north-seeking pole* of the compass deflects. The compass needle consists of nothing more than a small permanent magnet, usually with its *north-seeking pole* painted black, to distinguish

it from its *south pole*. The magnetic field around the conductor will react upon the magnetic field produced by the compass needle, so that the magnetic fields of the compass and the conductor coincide. The magnetic action always causes

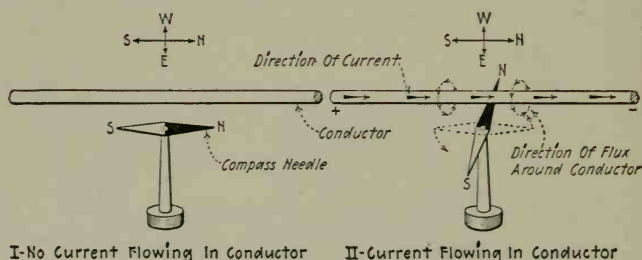


FIG. 230.—Diagram showing the effect on a compass needle, of the magnetic field around a conductor which is carrying an electric current. This principle can be applied in determining the polarity of a current-carrying conductor.

the north pole to point in the direction of the magnetic field. Then by applying the right-hand rule (Sec. 361) to the conductor, the polarity of the conductor can be determined.

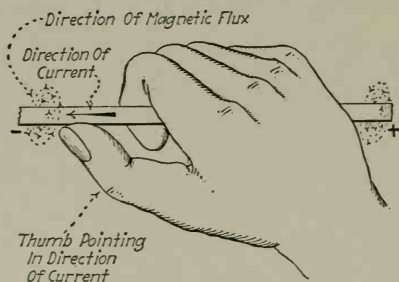


FIG. 231.—Application of right-hand rule for determining the direction of current in a conductor, knowing the direction of the magnetic flux around the conductor.

361. NOTE.—POLARITY MAY BE DETERMINED BY THE “RIGHT-HAND RULE.” That rule is: If a wire through which an electric current is flowing is grasped in the right hand (Fig. 231) so that the fingers will point in the direction of the magnetic field, then the thumb points in the direction of the current flow. The magnetic field always lies at right angles to the conductor. Figures 231 and 232 illustrate the above principles. For a more complete explanation of electromagnetism see author's “Practical Electricity,” Sec. 9.

362. EXAMPLE.—TO DETERMINE THE POLARITY OF A CONDUCTOR WITH A COMPASS (Fig. 232) a current of at least approximately 5 amp. should flow through the conductor. The compass is then placed either

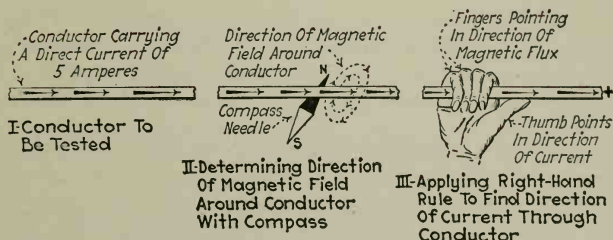


FIG. 232.—Progressive steps for determining the polarity of a current-carrying conductor by the compass method.

above or below the conductor and the direction in which the *north* pole of the compass needle points is noted (Fig. 232-II). This indicates the direction of the magnetic field around the conductor. The right-hand rule is then applied to the conductor (Fig. 232-III) and the direction of the current flow through the conductor is determined, as is the polarity.

363. EXAMPLE.—A SIMPLE MAGNETIC POLARITY INDICATOR can be easily constructed from a discarded telephone ringer (Fig. 233). The throw of the needle or pointer may be increased by adjusting the armature of the ringer. A switch is provided to make and break the circuit through the ringer coils. The switch also acts as a safeguard against burning the coils out in case the resistance of the coils is too small for the potential of the circuit which is being tested. The pointer is provided with a white paper disc having the polarity indication (+ or -) marked upon it. Whether the mark should indicate *positive* (+) or *negative* (-) will depend upon the direction of the winding of the coils and the polarity of the magnets. This can best be determined by testing out a circuit of which the polarity is known and marking the pointer accordingly.

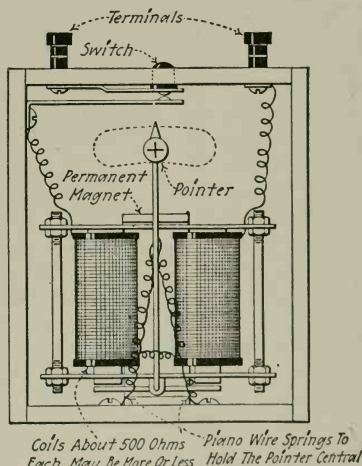


FIG. 233.—A simple and useful magnetic polarity indicator constructed from a polarized telephone bell-ringer.

To determine the proper marking of the pointer, connect the binding posts of the polarity indicator to a circuit of which the polarity is known. The pointer will then be deflected, pointing to one of the binding posts. The polarity of the binding posts to which the pointer points should be observed and the symbol for the polarity of the conductor connected to the binding post should be marked upon the pointer. When connected to a direct-current circuit the pointer will thereafter always point to the binding post the polarity of which corresponds to that which is marked on the pointer.

364. EXAMPLE.—A DIRECT-CURRENT VOLTMETER CAN BE USED AS A POLARITY INDICATOR (Fig. 234). The voltmeter must be of the D'Arsonval type, that is, one which has a movable coil and a permanent magnet.

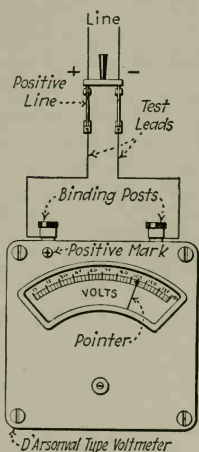


FIG. 234.—Diagram showing method of determining polarity with a voltmeter.

The *positive* (+) binding post of such an instrument is always marked. By connecting the terminals of a circuit (Fig. 234), of which the polarity is desired, to the binding posts of the voltmeter, the pointer of the voltmeter will move over the scale in the correct direction providing the positive (+) terminal of the circuit is connected to the positive (+) binding post of the voltmeter. Therefore, if the needle of a voltmeter moves over the scale in the correct direction when the terminals of a circuit are connected to its binding posts, the terminal connected to the *positive* (+) binding post of the voltmeter will be the *positive* (+) conductor and the other conductor will be the *negative* (−) conductor. If the needle tends to move backward, the positive terminal of the circuit is connected to the negative terminal of the voltmeter.

365. NOTE.—WHEN TESTING A CIRCUIT FOR POLARITY BY THE VOLTMETER METHOD, precaution should be taken to see that the potential of the circuit, which is to be tested, does not greatly exceed the full-scale value of the voltmeter. If the potential of the circuit exceeds the full-scale value of the voltmeter, a suitable multiplier or resistance must be inserted with the voltmeter so that the voltage across the instrument is within its range.

366. NOTE.—ANOTHER METHOD OF DETERMINING THE POLARITY OF A CIRCUIT THE POTENTIAL OF WHICH EXCEEDS THE RANGE OF THE VOLTMETER (Fig. 235) is as follows: Connect a number of lamps in series, depending upon the voltage rating of the lamps and the voltage of the circuit, across the circuit to be tested. Then connect the voltmeter across one lamp and determine from the deflection of the pointer, the polarity of the circuit.

367. NOTE.—A POCKET KNIFE PROVES A USEFUL TOOL FOR EFFECTING CONNECTIONS BETWEEN A TEST-WIRE LEAD AND AN INSULATED

CONDUCTOR.—If the bared test wire is clamped under the small blade of the knife, as shown at *A*, Fig. 236, the large blade can be cut through the insulation and brought into contact with the conductor under test,

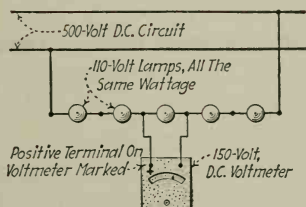


FIG. 235.—Diagram illustrating method of determining the polarity of a circuit with a voltmeter which has a range less than the potential of the circuit.

as shown at *B*. The slit in the insulation at *B* can be taped over after the test. This method renders it unnecessary to “skin” an insulated conductor. This is important if the test is being made in a restricted space, as in a conduit outlet box.

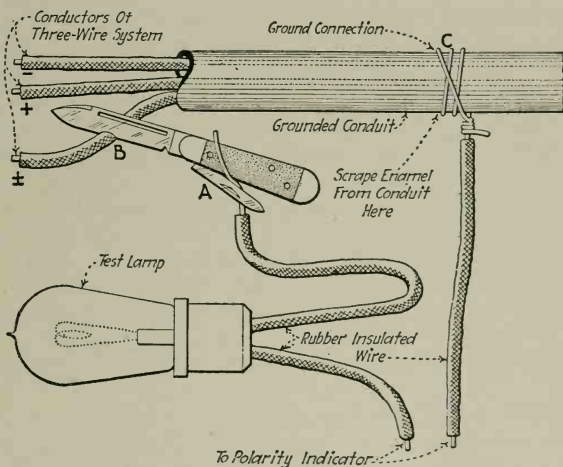


FIG. 236.—A knife used as a feeler.

Figure 236 also illustrates a process of ascertaining which is the *neutral conductor of a three-wire circuit*. Neutral conductors always are, or should be, grounded. Furthermore, the conduit in a wiring system should be grounded. Hence, the connection *C* of one of the lead wires of a polarity indicator to the conduit is in reality a connection to ground. If with the knife blade at *B* in contact with any one of the three conductors, no bubbles appear in the polarity indicator, the wire to which the

knife blade is then attached must be the neutral wire. Which is the positive and which the negative wire can be easily ascertained by successively cutting the knife blade into contact with each and noting the indication of the polarity indicator.

368. NOTE.—THE FOREGOING TESTS ARE APPLICABLE ONLY ON DIRECT-CURRENT CIRCUITS.—Hence if there is any question, before one proceeds he should determine whether the circuit is direct or alternating current. Where the voltage does not exceed 110, or possibly 220, an experienced man can identify an alternating current circuit by “feeling,” with the first finger of each hand or with the thumb and first finger of one hand, across the bared conductors of opposite polarity. With an alternating-current circuit the shock that results may be likened to a series of impulses and it causes a vibrating sensation in the fingers. Conversely, the shock from a direct-current circuit will be continuous or steady in character. It is not advisable, because of the possible danger to life, to test circuits involving voltages higher than 220 by feeling with the fingers.

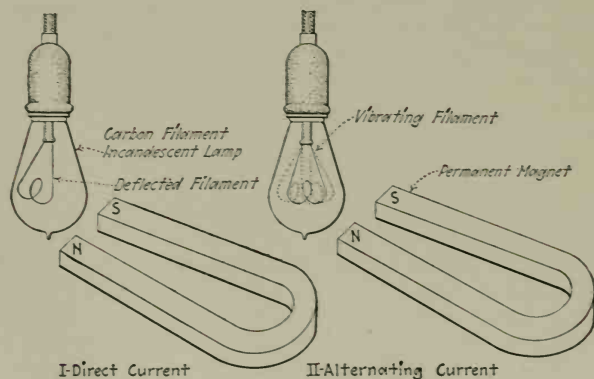


FIG. 237.—Magnet method of distinguishing between a direct and an alternating current.

369. NOTE.—IF A DIRECT-CURRENT, PERMANENT-MAGNET TYPE OF VOLTMETER IS AVAILABLE (Fig. 234), it may be connected across the circuit under test. If it is a direct current circuit the voltmeter needle will deflect, indicating the voltage. But if it is alternating current the needle will only vibrate slightly. A carbon filament incandescent lamp may be used in conjunction with a strong horseshoe magnet (a bar magnet

will do), to indicate whether the circuit from which the lamp is fed is alternating or direct current. On a direct-current circuit, the lamp being illuminated by the current flowing through its filament, if a magnet is carried near the filament it will be deflected steadily in one direction, as indicated in Fig. 237-II. But if the current is alternating, the filament will vibrate (Fig. 237-U) to and fro with a frequency equal to the frequency of the circuit. Metallic-filament lamps cannot be used in making this test because their filaments are so supported that they are not free to vibrate.

QUESTIONS ON DIVISION 6

1. Define *polarity*, when the term is used with reference to an electric circuit.

2. Give an explanation of the *positive* (+) conductor of an electric circuit. The *negative* (−) conductor.

3. When is it desired to know the polarity of an electric circuit?

4. Give several examples where polarity of an electric circuit must be known to properly connect devices to a circuit. Use diagrams to illustrate the examples.

5. Under what general headings can the more common methods of determining polarity be classified?

6. Explain the electro-chemical method of determining polarity with a salt-water or an acid solution.

7. Describe the method of constructing a polarity tester for low battery voltages. For circuits of different voltages. Use diagrams in your descriptions.

8. How can fuse wire be used to an advantage for electrodes of certain types of polarity indicators?

9. How can an electric incandescent lamp be converted into an electric polarity indicator?

10. Describe the blue-print paper method for determining the polarity of a circuit. The potato method.

11. How can a solution of iodide of potassium be employed in a polarity indicator?

12. Explain the electromagnetic method of determining polarity.

13. Explain the compass method of determining polarity. What is the right-hand rule for ascertaining polarity?

14. How can a voltmeter be used to find the polarity of a circuit?

15. What precautions should be taken when using a voltmeter for determining the polarity of a circuit?

16. Illustrate the procedure of determining polarity of a circuit by the voltmeter method, when the potential of the circuit exceeds the range of the voltmeter.

17. How can a pocket knife be employed as a useful tool for affecting connections between a test-wire lead and an insulated conductor, without skinning conductor?

18. Describe the voltmeter method of distinguishing a direct- from an alternating-current circuit.

19. How can a carbon-filament lamp and a bar magnet be employed to distinguish an alternating- from a direct-current circuit?

SOLUTION TO PROBLEMS ON DIVISION 2

Locating Faults in Multiple Transmission and Distribution Circuits

1. By Sec. 115, the distance to the fault $= 29,300 \times 0.425 = 12,452$ ft.

2. By Sec. 119, the distance to the fault $= (259 \times 2 \times 21,200) \div 1,000 = (259 \times 42,400) \div 1,000 = 10,980$ ft.

3. By Sec. 121, the distance to the fault $= 6,780 \times 0.86 = 5,830$ ft.

4. By For. (18), the distance to the fault,

$$D = L \frac{2B}{A + B} = 9,400 \frac{2 \times 2.62}{4.12 + 2.62} = 9,400 \times \frac{5.24}{6.74} = 7,308 \text{ ft.}$$

5. By For. (27), the distance from the point of test to the open-circuit,

$$D = \frac{L}{2} \left(\frac{X}{100 - \frac{X}{2}} \right) = \frac{18,200}{2} \left(\frac{46.4}{100 - (46.4 \div 2)} \right) = 9,100 \times \frac{46.4}{76.8} = 5,498 \text{ ft.}$$

6. By For. (31), the distance to the fault, $D = \frac{X}{100} L = \frac{66}{100} \times 34,600 = 66 \times 346 = 22,836$ ft.

7. By For. (35), the distance to the fault, $D =$

$$\frac{L}{2} \left(4 - 3 \frac{X}{100} \right) = \frac{24,600}{2} \left(4 - 3 \times \frac{72}{100} \right) = 12,300 \times (4 - 2.16) = 12,300 \times 1.84 = 22,632 \text{ ft.}$$

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